

**Water Resources Research Center
Annual Technical Report
FY 2013**

Introduction

A Research and Extension unit of the College of Agriculture and Life Sciences, the University of Arizona Water Resources Research Center (WRRC) has a mission to promote understanding of critical state and regional water management and policy issues through research, outreach and education. It accomplishes its mission by assisting communities in water management and policy; educating teachers, students and the public about water; and conducting scientific research on state and regional water issues. The WRRC is known statewide as a hub for water resources research and information transfer in Arizona. It is the designated state water resources research institute established under the 1964 Federal Water Resources Research Act, and as such, the WRRC administers research grant programs, conducts water management and policy research, and runs a strong information transfer program that includes publications, presentations, conferences and other public events. In addition to these activities, the WRRC conducts programs of research on topics such as statewide water planning, environmental water needs, conservation, water harvesting, and transboundary groundwater management and governance. Collaborations and cooperative arrangements are vital for accomplishment of the WRRC's active research, education and outreach goals. Among its key partners is the Water Sustainability Program, one of three programs making up the Water, Environmental and Energy Solutions (WEES) program, which is housed at the WRRC and funded from the UA's Technology and Research Initiative Fund (TRIF). The WRRC also houses Arizona Project WET (Water Educations for Teachers), which was initiated at the WRRC in 1991. Arizona Project WET is Arizona's premier water education program. In addition the WRRC is closely linked with Arizona Cooperative Extension.

Research Program Introduction

The University of Arizona WRRC provides support through the WRRRA, Section 104(b) research grant program in the form of research grants to investigators at the three state universities in Arizona. The WRRC typically funds three or four research projects that investigate water issues judged to have statewide importance. A wide range of projects have been funded over the years, emphasizing mandated program goals of improving water supply reliability and quality, and exploring new ideas to address water problems and expanding understanding of water and water-related phenomena. In the project year 2013-2014, the WRRC again called for proposals that address these goals.

During the project year (March 2012 through February 2013) the WRRC funded three projects proposed by University of Arizona investigators and one from ASU. Water management is increasingly a negotiated process that requires hydrologic information in a form that makes uncertainty manageable. One project developed an integrative framework for working with multiple user groups while reducing uncertainty in hydrologic forecasts by identifying the data with the greatest impact. A tool for risk-based decision support, the framework may be applied for real-world management and stakeholder negotiations.

The majority of the projects examined wastewater quality and treatment. Recycled water is considered a major source for new water supplies in Arizona as demands for scarce water resources increase. Quality concerns are a major impediment to more widespread use of recycled water and research is needed on a multitude of water quality issues relating to the occurrence, prevalence and reduction of contaminants. New methods of detection, measurement and treatment are necessary.

Of the three water quality related projects, one investigated a simple method for eliminating antibiotic resistant pathogens in treated municipal recycled water. The study was designed to provide information for development of treatment strategies to reduce the release of multi-resistant bacteria into the environment.

Another project also focused on wastewater recycling in an examination of potential synergy between advanced oxidation and soil-aquifer treatment for removal of trace organic contaminants in treated wastewater. The combination of engineered and natural processes offers the potential of reduced costs for providing equal or better water quality as engineered processes alone.

The final funded project extended applications of extraction methods (LLE and SPE) to extracting nanoparticles from environmental water samples. The project was designed to provide a robust protocol for rapid extraction and quantification and enable better understanding of how nanoparticles behave in complex aqueous environments.

Reports on the following research projects are included in this Annual Technical Report:

2008AZ366S - Cooperative Agreement--Transboundary Aquifer Assessment Program

2013AZ512B - Do Simple Carbon Additions Reduce Resistance to Antibiotics in Environmental Bacteria?

2013AZ513B - Discrimination-Inference to Reduce Expected Cost Technique (DIRECT): A new framework for water management and stakeholder negotiation

2013AZ516B - Sequential Advanced Oxidation and Soil-aquifer Treatment for Management of Trace Organics in Treated Wastewater

2013AZ517B - Extraction Methods for Engineered Nanoparticles from Aqueous Environmental Samples

Research Program Introduction

2013AZ519S - Integrating African Hydrologic Initiatives Using Satellite Products to Support Water Monitoring and Forecasting in Africa

Cooperative Agreement--Transboundary Aquifer Assessment Program

Basic Information

Title:	Cooperative Agreement--Transboundary Aquifer Assessment Program
Project Number:	2008AZ366S
Start Date:	3/17/2008
End Date:	3/16/2013
Funding Source:	Supplemental
Congressional District:	AZ-7
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Management and Planning, None
Descriptors:	
Principal Investigators:	Sharon B. Megdal, Christopher A Scott

Publications

1. Megdal, Sharon B. 2007. "Front-Row View of Federal Water Lawmaking Shows Process Works – U.S. Mexico Transboundary Aquifer Assessment Act Pondered, Passed and Signed," Arizona Water Resource, January-February 2007.
2. Megdal, Sharon B. 2008. "Front-Row View of Federal Water Lawmaking Shows Process Works – U.S. Mexico Transboundary Aquifer Assessment Act Pondered, Passed and Signed" (updated/revised version of 2007 column), in Norman, Laura M., Hirsch, Derrick D., and Ward, A. Wesley, eds., 2008, Proceedings of a USGS Workshop on facing tomorrow's challenges along the U.S.-Mexico border; monitoring, modeling, and forecasting change within the Arizona-Sonora transboundary watersheds: U.S Geological Survey Circular 1322, <http://pubs.usgs.gov/circ/1322/>.
3. Scott, Christopher A., et al. 2009. "Assessment of United States – Mexico Transboundary Aquifers Facing Climate Change and Growth in Urban Water Demand" Climate Change (in press)
4. Alley, W.M., ed., 2013, Five-year interim report of the United States – Mexico Transboundary Aquifer Assessment Program: 2007 – 2012: U.S. Geological Survey Open-File Report 2013–1059, 31 p.
5. Callegary, J., Megdal, S.B., Scott, C.A., Vandervoet, P.L., 2013, Arizona/Sonora Section of the Transboundary Aquifer Assessment Program, in USGS Open File Report 2013-1059, 14 p.
6. dos Santos, Plácido, 2012, The Transboundary Aquifer Assessment Program (TAAP) in Arizona-Sonora / Programa para la Evaluación de Acuíferos Transfronterizos en Sonora-Arizona. Water Resources Research Center, 4p. Available at <http://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/TAAP%20Brochure%20Final%2023April2013.pdf>

Summary

The Transboundary Aquifer Assessment Program (TAAP) originates from U.S. Public Law 109-448, signed into law by the President of the United States on December 22, 2006 as the U.S.-Mexico Transboundary Aquifer Assessment Act. The Act applies to the states of Texas, New Mexico, and Arizona where four transboundary aquifers have been designated for priority assessment. These aquifers include the Hueco Bolson and Mesilla Basin aquifers in the greater El Paso / Ciudad Juárez region and the Santa Cruz and San Pedro aquifers across the Arizona – Sonora border (see map). TAAP is designated to operate for 10 years, with \$50 million authorized for appropriation over that time period. Appropriations to date include \$500,000 each for fiscal years 2008 and 2009 and \$1 million for 2010. By 2012 a total of only \$2 million had been appropriated for all four of the priority aquifers designated in the federal legislation. With no appropriations for 2013 or later, the program's remaining funding expired on March 15, 2013. Unless additional funds materialize for continuation of the program, this will be the final report provided by the University of Arizona (UA) Water Resources Research Center (WRRC.)



TAAP-A/S (Arizona/Sonora) conducts assessments of aquifers shared by Arizona and Sonora as a collaborative effort between the United States Geological Survey (USGS) and the University of Arizona, by way of the WRRC and the Udall Center for Studies in Public Policy. A variety of other U.S. and Mexican stakeholders participate in the priority- setting for the assessment process. TAAP-A/S (which studies the transboundary Santa Cruz and San Pedro aquifers) has participated in the UNESCO Internationally Shared Aquifer Resource Management (ISARM) Programme, which has led to TAAP participation in international conferences and a wider range of scientific resources.

During the November 2009 international TAAP workshop, the Transboundary Aquifer Assessment Program- Arizona and Sonora component developed a work plan for activities to be carried out during the 2010-11 program year. These activities were divided between responsibilities falling under the supervision of the Arizona Water Science Center of the USGS and those by the Water Resources Research Center (WRRC) and Udall Center for Studies in Public Policy (Udall), both at the University of Arizona. Activities carried out by the WRRC and Udall are classified under the heading of “vulnerability assessment” as they are focus on issues more closely related to groundwater use by and related to human populations. Activities supervised by the USGS come under the heading of “hydrological modeling framework”, as the work tends to focus on the purely hydrological and geological aspects of aquifers in question. The vulnerability assessment items (listed below in bold) aim to involve a varied socio-economic set of stakeholders that affect and depend upon groundwater resources located within the bi-national upper Santa Cruz and San Pedro river basins.

The evolving vulnerability related to groundwater use by urban centers such as Cananea, Sierra Vista, and Ambos Nogales, as well as surrounding rural communities and a proposed mine in the Mexican portion of the Santa Cruz Aquifer, is a significant issue for transboundary aquifers, given the proximity of aforementioned cities to the international boundary as well as their near total dependence on groundwater. Some of the issues particular to these areas include groundwater recharge deficit in the

Sierra Vista subwatershed, over-allotment of groundwater rights in the Mexican section of the San Pedro, storm runoff and wastewater (conveyance and treatment) infrastructure in Nogales, Sonora, and uncertainty regarding groundwater bearing and defining geological units around Nogales, Arizona well fields. Given these, as well as other unique regional issues, the vulnerability assessment for the TAAP-A/S work plan for project year 2012-13 focused on the following activities:

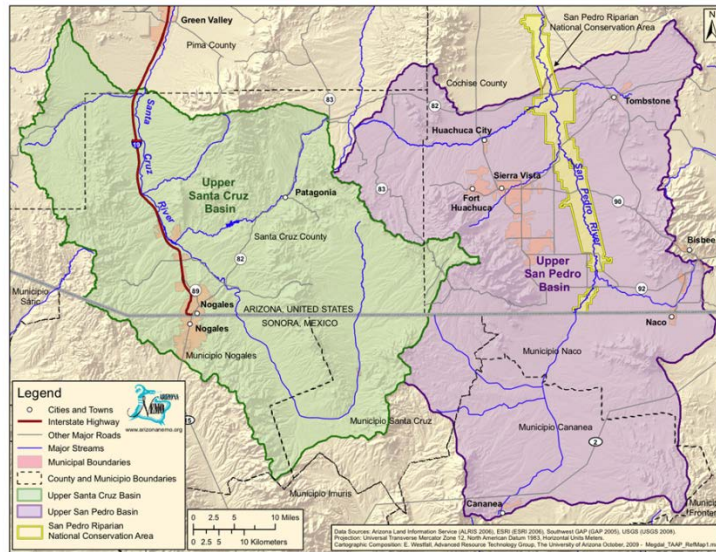
- A. Engagement with Mexican Project Partners
- B. Development of Binational GIS Products
- D. Development of Draft Reports for the San Pedro and Santa Cruz Aquifers
- C. Improved linkages with international best practices (via ISARM)

A. Engagement with Mexican Project Partners.

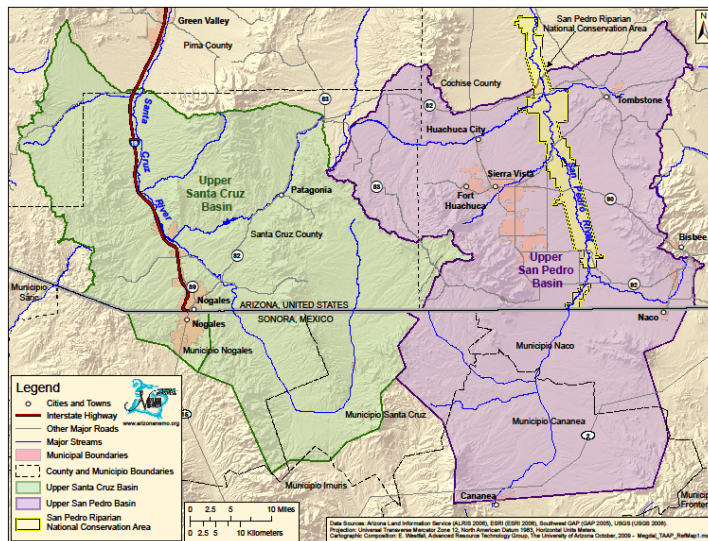
Activity description (2012-13 work plan): After a hiatus of Arizona-Mexico engagement on the TAAP's technical matters, the U.S. project partners reinvigorated bilateral discussions regarding the program to focus efforts on production of binational reports for the San Pedro and Santa Cruz Basins. Close binational coordination was needed among the USGS, University of Arizona, the University of Sonora, Mexico's National Water Commission and the International Boundary and Water Commission.

Summary of Activities Completed:

- The UA WRRC developed a new bilingual brochure describing the TAAP for use in Mexico and the U.S. The brochure is available at the UA WRRC's website:
<http://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/TAAP%20Brochure%20Final%2023April2013.pdf>
- The UA's TAAP representatives participated in the International Boundary and Water Commission's 2012 Binational Border Water Resources Summit in September 2012. The Summit's Recommendations and Conclusions cited a need to continue funding for *"the critical Transboundary Aquifer Assessment Program (TAAP), a cooperative Mexican-U.S. research project."*
- The renewed binational engagement that occurred during 2012 brought to light some significant differences regarding the project boundaries. As a result of this bilateral re-examination of the project boundaries, Mexican partners revised the project boundaries in both the San Pedro and Santa Cruz study areas to reflect the regulatory "aquifer" boundaries defined by CONAGUA for administrative purposes. The original project boundaries and the final project boundaries, which were adopted during 2012, are reflected on the Arizona-Sonora TAAP study area maps below.



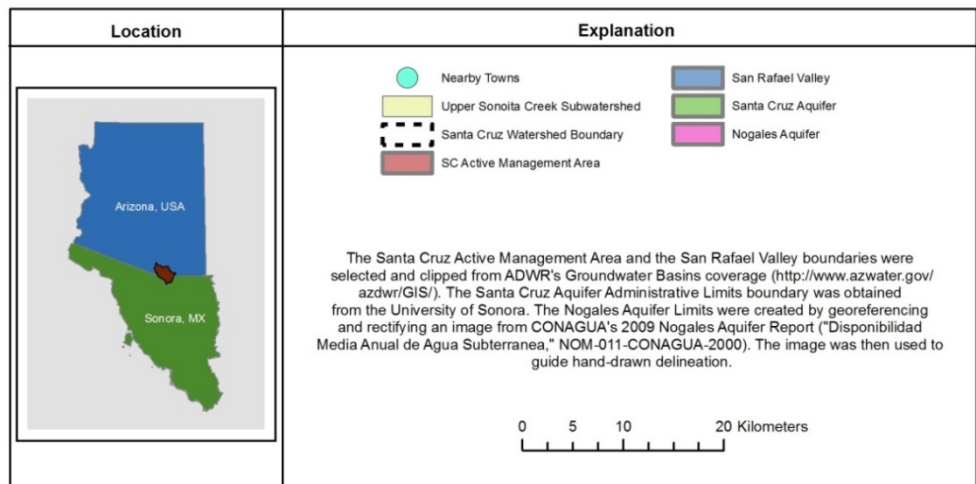
Map above depicts the project boundaries prior to 2012 bilateral engagement.



This map depicts the final project boundaries after 2012 bilateral engagement.

- In the re-examination of the technical scope of the binational assessments in the Arizona-Sonora region, another notable difference of interpretation came to light that required several months for resolution. At issue was the proposed exclusion of the Mexican portion of the Nogales Wash watershed. For regulatory purposes Mexican authorities define the Santa Cruz Aquifer as an administrative region which does not include the Nogales watershed. Consequently, the University of Sonora was contracted by the Mexican Section of the IBWC to perform a TAAP study of the Santa Cruz Aquifer, not including the Nogales Aquifer region. Although not considered to be a part of the Santa Cruz Aquifer, the involved parties recognized the hydrogeological connectivity of these two areas and concluded that both would be part of the Santa Cruz Aquifer TAAP study. The following map depicts the five regulatory subsets that were included in the Santa Cruz Aquifer TAAP study.

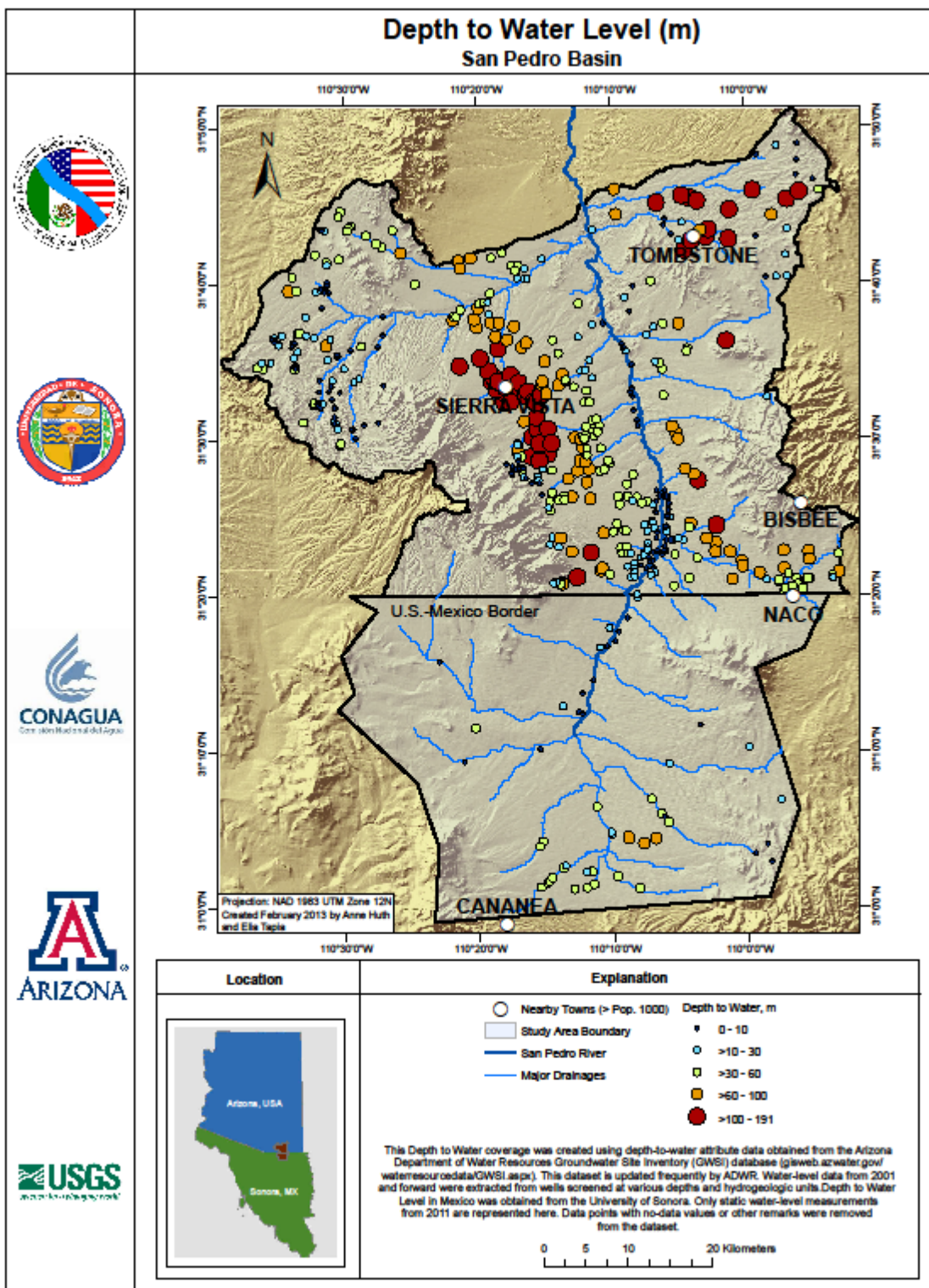
Regulatory Subsets of Study Area Santa Cruz Basin



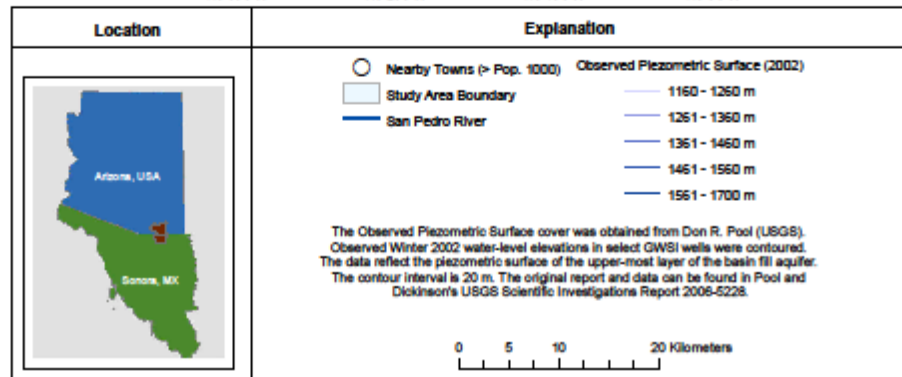
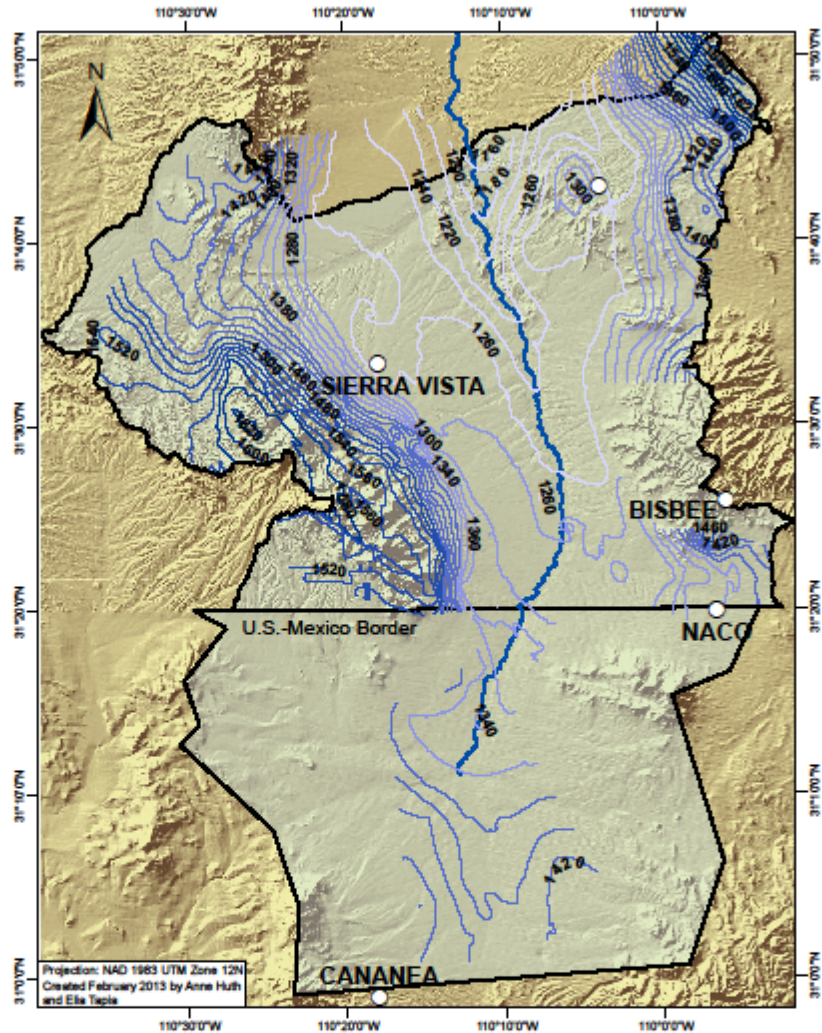
B. Development of Binational GIS Products

Activity description (2012-13 work plan): The UA WRRC awarded a contract for professional services to generate a series of binational GIS products for the TAAP effort in the Arizona-Sonora region. The contractor accessed GIS data layers archived with the USGS Water Science Center in Tucson as well as host of other data sets from locations such as the Arizona Department of Water Resources, the University of Sonora and other organizations as needed. The general categories of data handled by the contractor included geology, geophysics, land use, land cover, hydrology, hydrogeochemistry and climatic information. A total of over 60 GIS maps were generated, each map was accompanied by documented metadata and a database of all data sources used in the production of the maps. When finalized binationally for inclusion in the TAAP reports for the San Pedro and Santa Cruz aquifers, the maps, databases and metadata will all be posted at the IBWC's website since the reports will be binationally approved.

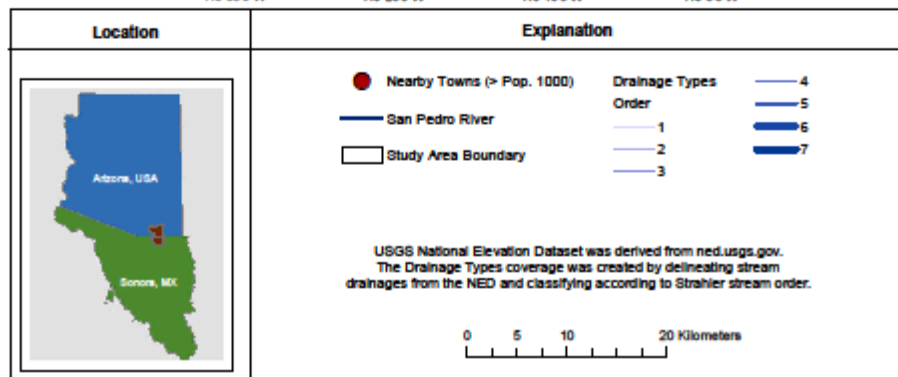
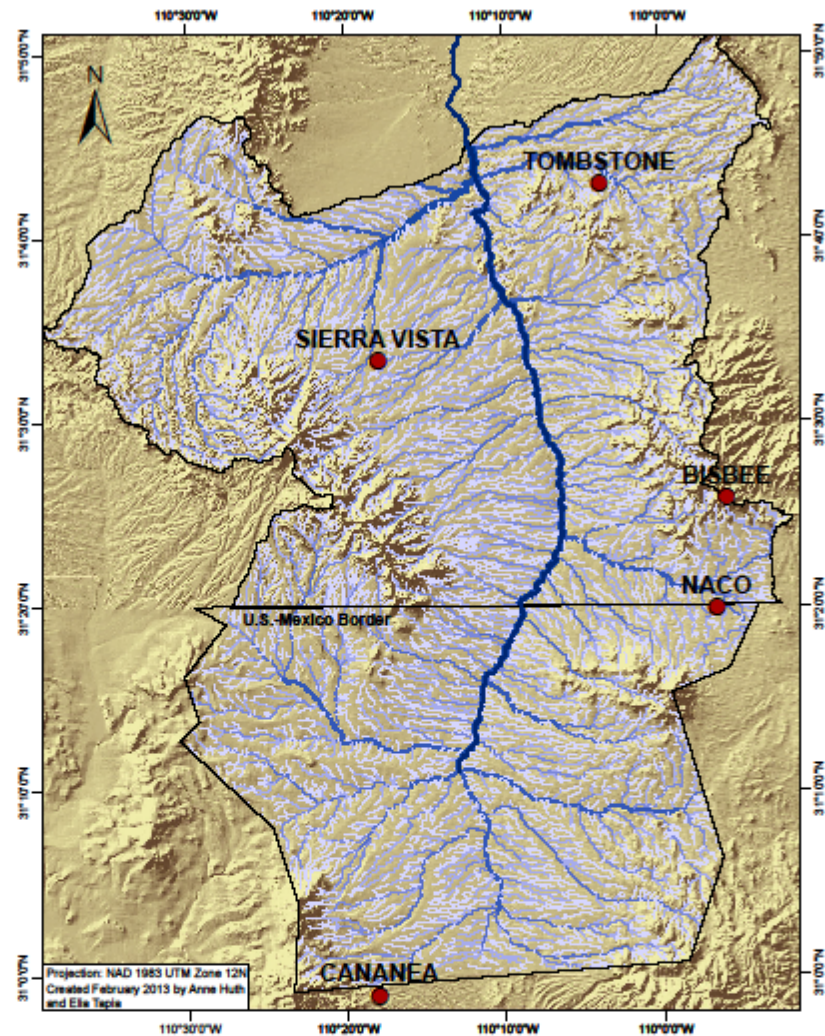
The binational maps that have been produced have never been attempted before and represent a level of bilateral data-sharing and collaboration that is precedent-setting along the U.S.-Mexico border. Several examples of the maps are included below. The complete data sets are archived as working files at the USGS, University of Sonora and the UA WRRC.



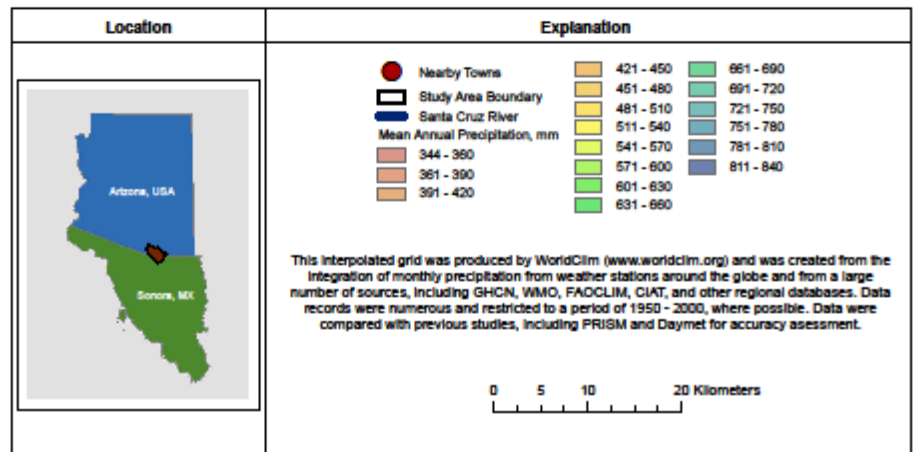
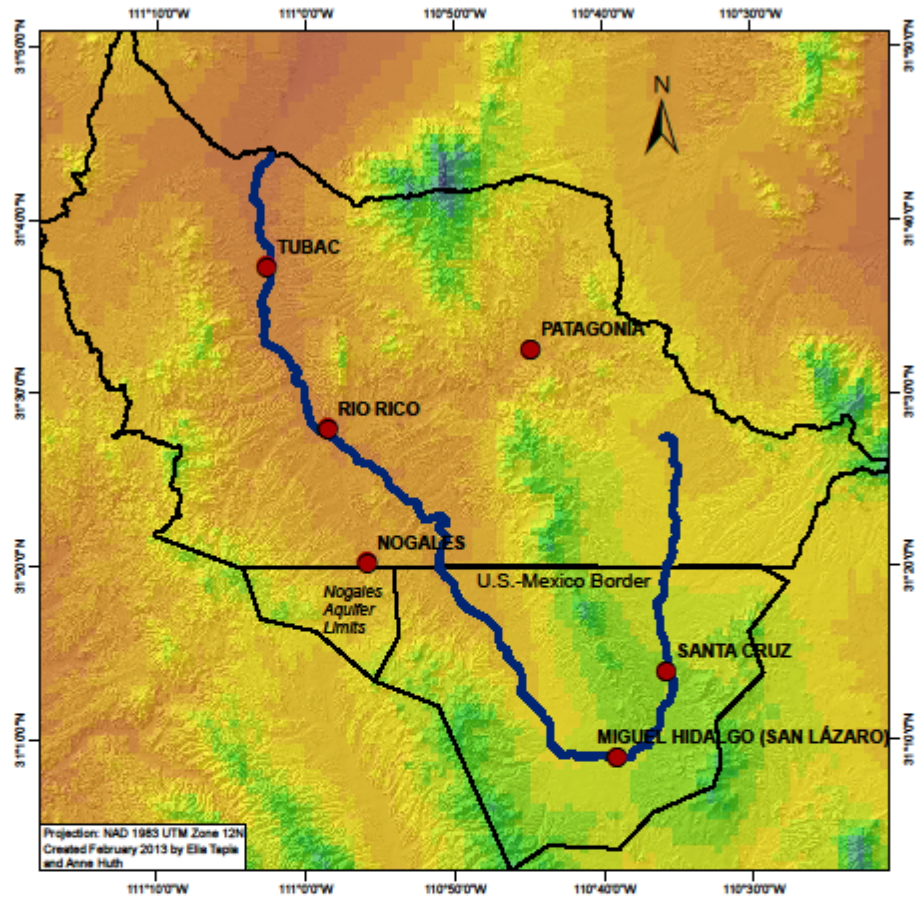
Observed Piezometric Surface San Pedro Basin



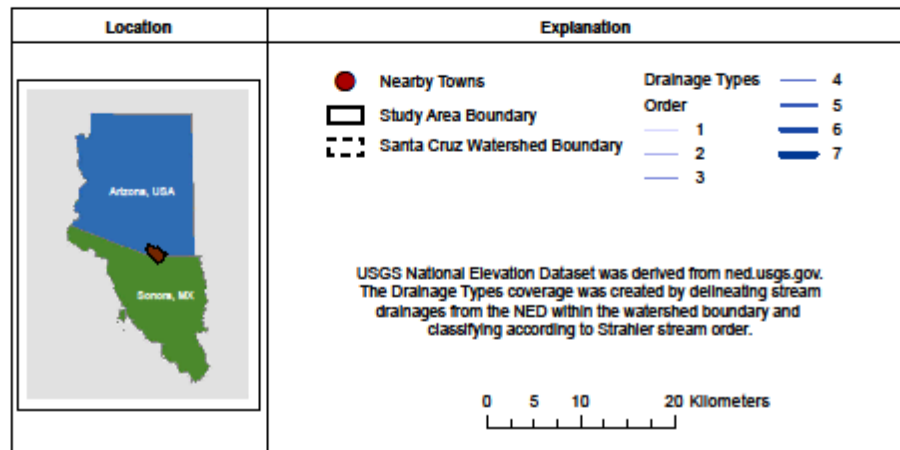
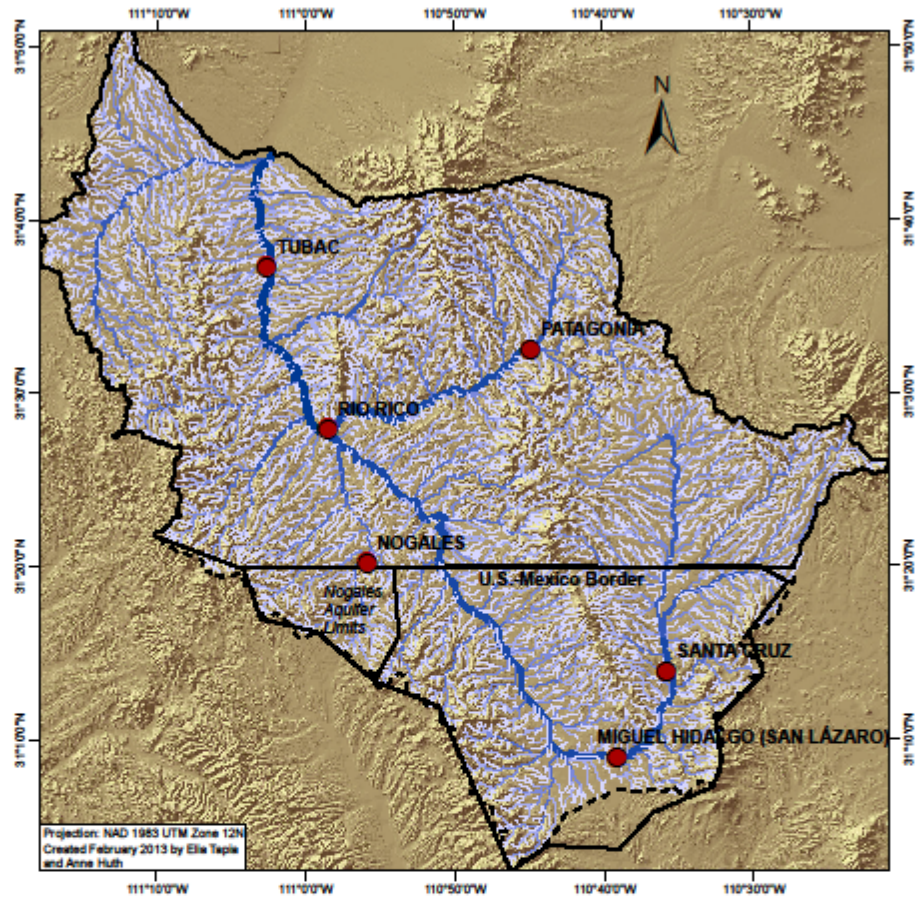
Drainage Types San Pedro Basin



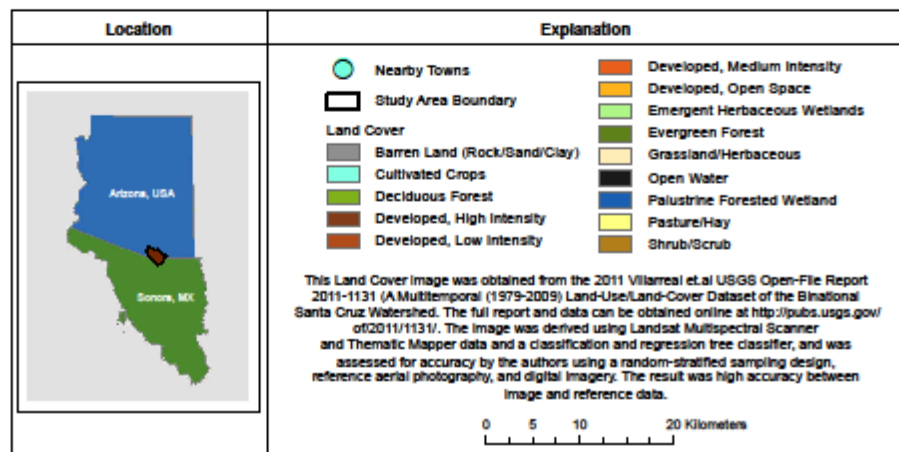
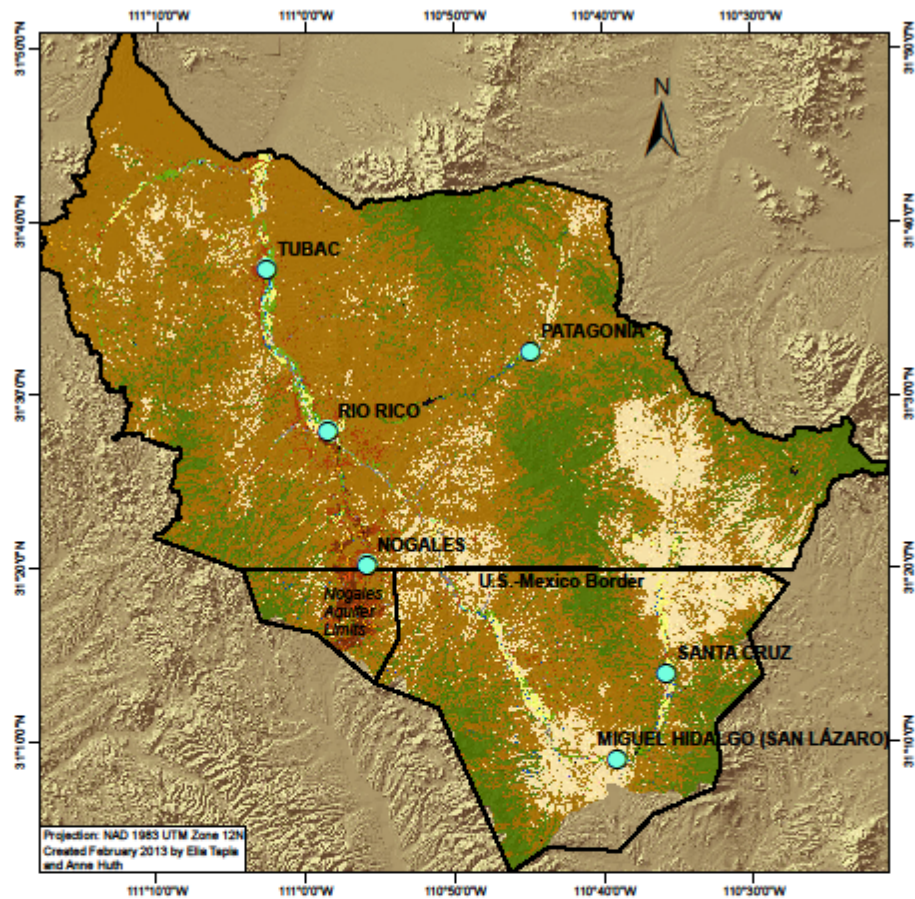
Mean Annual Precipitation (mm) Santa Cruz Basin



Drainage Types Santa Cruz Basin



Land Cover Santa Cruz Basin



C. Development of Draft Reports for the San Pedro and Santa Cruz Aquifers

Activity description (2012-13 work plan): The U.S. and Mexico participants in the Arizona-Sonora TAAP program, met during early 2012 and reached agreement on details regarding two reports that would be developed during the period 2012-2013. The parties were the USGS, Mexico's National Water Commission (CONAGUA), the University of Sonora's Department of Geology (UNISON), the University of Arizona Water Resources Research Center (UA WRRC) and the university's Udall Center for Studies in Public Policy, and the International Boundary and Water Commission's U.S. and Mexico Sections. The USGS, UNISON and UA WRRC agreed to write separate draft reports of the San Pedro and Santa Cruz aquifers during this year-long planning period. The authors would write in a single language, Spanish, in order to minimize translation needs and to facilitate the exchange of interim draft products. The parties also reached consensus on the outline that would be used for both reports. The English translation of the binationally adopted outline is presented below:

Prologue

Executive Summary

1. Introduction
 - i. Background
 - ii. Objectives
 - iii. Prior Studies
 - iv. Geographical Setting
 - v. Binational Socioeconomic Context
 - vi. Water Use
 - vii. Development Activities
 - viii. Methodologies and Techniques Used
2. Physiography, Climate
 - i. Physiographic Province
 - ii. Hydrography
 - iii. Hypsometry
 - iv. Terrain Slopes
 - v. Regional Climatic System
 - vi. Soils
 - vii. Vegetation
3. Hydrology, Hydrometeorology and Hydrogeomorphology
 - i. Climatological Analysis
 - ii. Precipitation and Evapotranspiration
 - iii. Surface Water Hydrology
 - iv. Drainage Types and Maximum Stream Order
 - v. Land Use and Other Land Cover Types
 - vi. Hydrogeomorphic Units
4. Conceptual Geologic Model
 - i. Regional Geologic Context
 - ii. Stratigraphy
 - iii. Structural Geology
 - iv. Geophysics
 - v. Subsurface Geologic Model

5. Piezometry and Hydraulic Parameters
 - i. Comprehensive Inventory of Wells (and Diversions?)
 - ii. Historic Reconstruction of Groundwater Pumping
 - iii. Analysis of the System's Piezometric Behavior
 - iv. Pump Tests
 - v. Definition and Interpretation of Subsurface Hydraulic Parameters
 - vi. Characteristics of Regional, Intermediate and Local Flow Systems
6. Hydrogeology
 - i. Hydrostratigraphic Units
 - ii. Hydrologic Basement
 - iii. Definition of the Aquifer System
7. Hydrogeochemistry
 - i. Hydrogeochemical Sampling
 - ii. Water Quality
 - iii. Determination of Dominant Water Types
 - iv. Distribution of Major Ions
8. Conceptual Model of Hydrodynamic Behavior
 - i. Geometry of the Groundwater System
 - ii. Hydraulic Parameters of Hydrostratigraphic Units
 - iii. Definition of Regional, Intermediate and Local Flow Systems
9. Conclusions and Recommendations

Summary of Activities Completed:

- All nine chapters of the Draft Transboundary Aquifer Assessment Report for the San Pedro Aquifer were written in the Spanish language by the USGS and the University of Arizona Water Resources Research Center. The US project partners shared the draft chapters with the University of Sonora for their review during January-March 2013. Binational comments were being integrated by the end of the reporting period.
- Chapters 1, 2, 3, 4 and 7 of the Draft Transboundary Aquifer Assessment Report for the Santa Cruz Aquifer were written in the Spanish language by the USGS and the University of Arizona Water Resources Research Center. The US project partners shared these chapters with the University of Sonora for their review during March-May 2013. Remaining chapters were under development at the time of writing with planned delivery to the Mexican partners by June 2013.
- Project participants from the UA WRRC and the UA Udall Center also contributed to the development of a 5-year report to the U.S. Congress regarding the TAAP. The USGS-issued Open-File Report, published in March 2013, is titled "Five-Year Interim Report of the United States-Mexico Transboundary Aquifer Assessment Program: 2007-2012." The report can be viewed here: <http://pubs.usgs.gov/of/2013/1059/>
- (for a complete list of TAAP publications and other output, see Annex A)

D. Improved linkages with international best practices (via ISARM)

Activity description (2012-13 work plan): Dr. Sharon Megdal and Dr. Chris Scott remained engaged with global and regional (Americas) ISARM initiatives. The Arizona-Sonora effort participates as a case study so as to provide other ISARM participants with information on TAAP as well as learning from other shared resource scenarios.

Summary of Activities Completed:

Dr. Sharon Megdal has engaged stakeholders and representatives of the Internationally Shared Aquifer Resource Management (ISARM) Programme of UNESCO, based in Paris, France. ISARM also maintains regional focus areas, in particular ISARM-Americas (centered in Montevideo, Uruguay), of which TAAP-A/S is recognized as a case study. Dr. Megdal has made presentations in Europe, the Middle East and South America at a variety of ISARM-related meetings and conferences detailing the particular issues related to the binational Santa Cruz and San Pedro aquifers as well as the role of TAAP-A/S in respect to bi-national cooperation related to hydrological assessment of the shared aquifer resources.

A variety of details make TAAP-A/S a unique initiative on the global level, namely the importance of groundwater as supply for potable water, growth rates of urban areas as well as the evolving roles of agriculture and mining/industry in the shared aquifer regions, and also the different governance strategies employed within the US and Mexico in respect to water resources. A main focus of Dr. Megdal's ISARM-related work has been to better understand the organizational asymmetries between water resource assessment and management agencies in the United States and Mexico. The degree of centralization as well as regulation and oversight is unique between the two nations, as well as the existence of the binationally coordinated International Boundary and Water Commission, which has a long history of coordinating resolutions related to the international border and shared waters of the U.S. and Mexico.

TAAP-A/S team members have supported further engagement between representatives of the US Geological Survey and the Mexican National Water Commission, as both agencies provide national representatives to the ISARM-Americas section of the global ISARM Programme. The communication medium of ISARM-Americas provides an excellent opportunity to share and learn from regional counterparts regarding common experiences. In the case of the US and Mexico, the shared border region contains many issues that would benefit from a binational perspective, in which ISARM-Americas may provide a medium in which to develop such a discussion.

Presentations:

Binational Assessment of the Santa Cruz and San Pedro Aquifers: Update of Arizona-Sonora collaboration under the Transboundary Aquifer Assessment Program (TAAP)

By James Callegary, Christopher Scott, Sharon Megdal and Plácido dos Santos. Presented at the Arizona-Mexico Commission Plenary Session - Water and Environment Committees, Tucson, Arizona; June 8, 2012

http://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/TAAP_Az-Mex_Commission_June_2012.pdf

The U.S.-Mexico Transboundary Aquifer Assessment Program (TAAP): Focus on the Arizona-Sonora collaboration. The Binational Assessment of the Santa Cruz and San Pedro Aquifers

By Plácido dos Santos. Presented at Binational Border Water Resources Summit: Past, Present and Future. Ciudad Juarez, Chihuahua, Mexico and El Paso, Texas, USA; September 28-29, 2012.

http://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/TAAP_Border%20Summit_Sep_2012%20Bilingual_2012_09_24.pdf

References

Alley, W.M., ed., 2013, Five-year interim report of the United States-Mexico Transboundary Aquifer Assessment Program: 2007–2012: U.S. Geological Survey Open-File Report 2013–1059, 31 p.

Arizona Department of Water Resources (ADWR). 2010. *Arizona Water Atlas: Volume 8- Active Management Area Planning Area*. Phoenix, Arizona.

Arizona Department of Water Resources (ADWR). 1999. *Third Management Plan for Santa Cruz Active Management Area, 2000-2010*. Phoenix, Arizona.

ADWR, Santa Cruz AMA. Accessed February 25, 2011.

<http://www.azwater.gov/dwr/WaterManagement/Content/AMAs/SantaCruzAMA/>

Coes, Alissa L. and Donald L. Pool. 2005. *Ephemeral-stream channel and basin-floor infiltration and recharge in the Sierra Vista subwatershed of the Upper San Pedro basin, southeastern Arizona*. USGS Open File Report 2005-1023.

Comisión Nacional del Agua (CNA). 2009a. *Actualización de la disponibilidad media anual de agua subterránea: Acuífero (2616) Río San Pedro, Estado de Sonora*. Subdirección General Técnica, Gerencia de Aguas Subterráneas, Subgerencia de evaluación y ordenamiento de acuíferos. Publicada de el Diario Oficial de la Federación el 28 de Agosto de 2009.

Comisión Nacional del Agua (CNA). 2009b. *Determinación de la disponibilidad de agua en el acuífero 2615 Río Santa Cruz, Estado de Sonora*. Subdirección General Técnica, Gerencia de Aguas Subterráneas, Subgerencia de evaluación y ordenamiento de acuíferos. México D.F. a Julio de 2009.

Comisión Nacional del Agua (CNA). 2007. *Determinación de la disponibilidad de agua en el acuífero Nogales (2650), Estado de Sonora*. Subdirección General Técnica, Gerencia de Aguas Subterráneas, Subgerencia de evaluación y ordenamiento de acuíferos.

Logan, Michael F. 2002. *The Lessening Stream: The Environmental History of the Santa Cruz River*. Tucson: University of Arizona Press.

Megdal, Sharon, Roberto Sención, Christopher A. Scott, Florencio Díaz, Lucas Oroz, James Callegary, Robert G. Varady. 2010. Institutional Assessment of the Transboundary Santa Cruz and San Pedro Aquifers on the United States – Mexico Border. UNESCO-IAH-UNEP Conference, Paris 6-8 December 2010.

Megdal, Sharon, Roberto Sención, Christopher A. Scott, Florencio Díaz, Lucas Oroz, James Callegary, Robert G. Varady. 2010. Evaluación Institucional de los Acuíferos Transfronterizos Santa Cruz y San Pedro en la Frontera México – Estados Unidos. UNESCO-IAH-UNEP Conference, Paris 6-8 December 2010.

Megdal, Sharon B. “The U.S.-Mexico Transboundary Aquifer Assessment Program: The Arizona-Sonora Portion as a Case Study.” Presentation given at World Water Week. August 20, 2009. Stockholm, Sweden.

Megdal, Sharon B. “Institutional Mechanisms for the Assessment and Management of Transboundary Aquifers: The Importance of Partnerships.” Presentation given at the Scientific Segment of the 19th Session of the International Hydrological Programme Intergovernmental Council. July 7, 2010. Paris, France.

Nelson, Keith E. and Gretchen Erwin. 2001. Santa Cruz Active Management Area 1997-2001 Hydrologic Monitoring Report. Arizona Department of Water Resources. Phoenix, Arizona.

Scott, Christopher A., Sharon B. Megdal, Lucas Antonio Oroz, James Callegary, Prescott Vandervoet, (in review) Assessment of the United States – Mexico Transboundary Aquifers: Facing Climate Change and Growth in Urban Water Demand. Climate Research- Special Issue on Border Climate Change.

Towne, Douglas C. 2003. *Ambient Groundwater Quality in the San Rafael Basin: A 2002 Baseline Study*. Arizona Department of Environmental Quality. Open File Report 2001-01. Phoenix, Arizona.

Vandervoet, Prescott. TAAP-A/S Santa Cruz Database. MS Access/MS Excel/PDF Format. Location: <http://www.cals.arizona.edu/azwater/taap>

Vandervoet, Prescott. TAAP-A/S San Pedro Database. MS Access/MS Excel/PDF Format. Location: <http://www.cals.arizona.edu/azwater/taap>

Vandervoet, Prescott L., Sharon B. Megdal, Christopher A. Scott. (In Review) *Los acuíferos transfronterizos Santa Cruz y San Pedro entre Arizona y Sonora: Estado Actual y Creación de Base de Datos*. Fortaleciendo el Dialogo Social: Desarrollo humano transfronterizo en la región Sonora-Arizona. Selected proceedings from the Bi-National colloquium hosted by the University of Sonora and Colegio de la Frontera. Nogales, Sonora May, 2010.

Upper San Pedro Partnership (USPP). 2007. Water Management of the Regional Aquifer in the Sierra Vista Subwatershed, Arizona- 2007 Report to Congress.
http://www.uspppartnership.com/lib_study_321.htm (18 de octubre de 2010)

Zheng, C. and P.P. Wang, 1999, [MT3DMS](#): A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide, Contract Report SERDP-99-1, U.S. Army Corps of Engineers Research and Development Center, Vicksburg, MS.

Do Simple Carbon Additions Reduce Resistance to Antibiotics in Environmental Bacteria?

Basic Information

Title:	Do Simple Carbon Additions Reduce Resistance to Antibiotics in Environmental Bacteria?
Project Number:	2013AZ512B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	AZ007
Research Category:	Biological Sciences
Focus Category:	Waste Water, Toxic Substances, Ecology
Descriptors:	recycled water, biosolids, antibiotic resistance
Principal Investigators:	Jean E.T. McLain, Channah Rock

Publication

1. McLain, J.E., C.F. Williams (2014) Development of antibiotic resistance in sediments following long term recharge with reclaimed wastewater. Sustainability, 6: 1313–1327; DOI: 10.3390/su6031313.

Final Report for 104b Project: Do Simple Carbon Additions Reduce Resistance to Antibiotics in Environmental Bacteria?

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Statement of Problem. Antibiotic-resistant pathogens are profoundly important to human health. A 2000 World Health Organization report focused on antibiotic resistance as one of the most critical human health challenges of the next century and heralded the need for a “global strategy to contain resistance” (WHO, 2000). According to the report, more than 2 million Americans are infected each year with resistant pathogens, and 14,000 die as a result.

Antibiotics are released daily into the natural environment in treated recycled water and through application of municipal biosolids onto agricultural fields (Halling-Sorensen et al., 1998; Dhanapal and Morse, 2009). Many of these compounds can now be readily detected in surface water resources (Kolpin et al., 2002; Yang and Carlson, 2003), leading to increasing concerns regarding their contribution to the presence and persistence of resistance in populations of both pathogenic and non-pathogenic microbes. However, there have been mixed results as to the impact of wastewater treatment on the proliferation of antibiotic resistance, with some studies showing that treatment processes increase the proportion of resistant bacteria (Murray et al., 1984) while others found no significant difference (Da Costa et al., 2008), or in some cases even a decline, between inflow and treated wastewater (Baquero et al., 2008).

Treated municipal recycled water is the only growing water sector in the state of Arizona. According to Arizona Department of Water Resources (ADWR), recycled water currently accounts for 4% (~260,000 acre-feet) of Arizona’s total water supply, and this percentage is expected to increase (ADWR, 2010). Currently, recycled water in Arizona is used directly for industrial cooling, irrigation (golf course, municipal, agricultural), constructed wetlands, and permitted recharge. In addition, more than 30 communities within the state currently hold permits for application of municipal biosolids, accounting for more than 80,000 dry tons of land application per year (ADEQ, 2003).

Such high environmental usage of recycled water and biosolids throughout Arizona, and the fact that applications tend to be higher near populated areas, increases concern on their effects on development of antibiotic resistance in the soil, and the potential for this resistance to move into the human food chain. However, very few data exist on the long-term effects of recycled water and biosolids application on resistance development and thus, it remains a significant research challenge to determine which factors induce resistance spread in soils, information which will be critical in the development of regulations focused on protection of public health.

One of the greatest challenges in researching environmental resistance development is the high level of “natural” resistance in soil microbes. Most antibiotics are produced by strains

of fungi and bacteria that occur naturally in soil, and antibiotic-producing strains carry genes encoding resistance to the antibiotics that they produce (Hopwood, 2007; Tahlan et al., 2007). The purpose of natural antibiotic production by soil microbiota is a matter of great scientific debate, but it has been suggested that antibiotics serve as signaling molecules that trigger beneficial responses for the microorganisms involved. For example, Linares et al. (2006) reported that low levels of antibiotics increased bacterial motility in environmental isolates. Such increased motility could enhance access of the antibiotic-producing microbe to scarce food supplies (organic molecules) within the soil. Little is known about the antibiotic resistomes of the vast majority of environmental bacteria, but it is widely recognized that there is a need for greater understanding of the environmental reservoirs of antibiotic resistance due to their potential impacts on clinically relevant bacteria.

Our research team has been examining the effects of long-term (20+ years) application of recycled municipal wastewater and biosolids on the development of antibiotic resistance in soils. These studies have been conducted at long-term ecological research sites in Gilbert, Arizona (recycled water application) and Austin, Texas (biosolids application). Through the multi-year study an intriguing pattern has emerged in bacteria isolated from soil samples collected at both sites. Though no increase in antibiotic resistance in environmental isolates has been observed to date, isolates at both locations show a marked decrease in multiple-antibiotic resistance in sites receiving long-term recycled water and biosolids application. This is potentially a very significant finding, as multiple-antibiotic resistant bacteria of clinical concern include “flesh-eating” *Enterococcus* and *Staphylococcus*. We hypothesize that the long-term application of recycled water and biosolids has increased soil organic carbon reserves and this has, in turn, decreased bacterial competition for organic molecules and decreased the necessity for bacterial antibiotic production. This study examined this hypothesis in a laboratory setting. A detailed assessment of the potential for abatement of multiple-antibiotic resistance may help to alleviate environmental and public health concerns regarding the use of recycled water and biosolids to augment water and soil carbon supplies in Arizona.

Research Objectives.

- Examine the effects of a range of carbon substrates on reducing or eliminating resistance to multiple antibiotics within bacterial isolates, with a focus on conditions that may be encountered by multiple-antibiotic resistant bacteria in soils during recycled water or biosolids application.
- Provide laboratory training in microbial cultivation and antibiotic resistance analysis for undergraduate students.
- Analyze all data to assess the potential for this study to provide utilities with new knowledge and tools for treatment process optimization for antibiotic resistance mitigation.

Methodology. In the first steps of the study, 20 multiple-antibiotic resistant (resistant to more than 4 antibiotics) isolates were identified for inclusion in this study. Antibiotics of interest and their current clinical resistance levels are listed in Table 1. All isolates were

bacteria of the genus *Enterobacteriaceae*, ubiquitous Gram-negative indicators of the sanitary quality of foods and water. Although not all *Enterobacteriaceae* are pathogenic, some can cause serious illness in humans, and they have long been shown to house antibiotic resistance (Cooke, 1976).

Table 1. Antibiotics utilized in this study to screen for resistance. Each antibiotic was tested in a range of dilutions (column 2); growth detected at antibiotic concentrations listed in column 3 indicates resistance to that antibiotic.

Antibiotic (Abbreviation)	Range Tested ($\mu\text{g mL}^{-1}$)	Resistance ($\mu\text{g mL}^{-1}$)
Amikacin (AMK)	8-64	≥ 64
Ampicillin (AMP)	4-32	≥ 32
Ampicillin/sulbactam (AMP/SUB)	4-32/2-16	$\geq 32/\geq 16$
Aztreonam (AZT)	8-32	≥ 32
Cefazolin (CFZ)	4-32	≥ 32
Cefepime (CFP)	4-32	≥ 32
Cefotetan Na (CFN)	8-32	≥ 32
Ceftriaxone (CFT)	1-64	≥ 64
Ceftazidime (CFD)	1-32	≥ 32
Cefoxitin (CFX)	4-32	≥ 32
Cefuroxime (CFM)	4-32	≥ 32
Ciprofloxacin (CIP)	0.5-4	≥ 4
Gentamicin (GEN)	2-16	≥ 16
Imipenem (IMP)	2-16	≥ 16
Gatifloxacin (GAT)	1-8	≥ 8
Meropenem (MER)	1-8	≥ 8
Piperacillin (PIP)	16-128	≥ 128
Nitrofurantoin (NIT)	16-128	≥ 128
Piperacillin/tazobactam (PIP/TAZ)	16-128/4	$\geq 128/\geq 4$
Ticarcillin/clavulanic acid (TIC/CLA)	16-64/2	$\geq 64/\geq 2$
Tobramycin (TOB)	4-8	≥ 8
Trimethoprim/sulfamethoxazole (TRI/SUL)	0.5-4/9.5-76	$\geq 4/\geq 76$
Cefpodoxime (CEF)	2-16	≥ 16

Initial screening of each isolate to establish resistance consisted of growing the bacterium in pH-buffered EC broth, with antibiotic added at the target resistance level (Table 1, column 3). The broth-antibiotic-isolate tube was placed into a shaking incubator at 37°C for 24 hour, and growth assessed by adding 100 μL of the broth to a microplate and reading on a spectrophotometer (BioTek, Inc.) at a wavelength of 600 nm (Quigley, 2009). Cell growth at the target resistance level (Table 1) was recorded as resistant. Only isolates resistant to 4 or more antibiotics were included in the study.

Following initial screening, each multiply-resistant isolate was cultivated buffered EC broth, with addition of a single carbon-substrate. Carbon substrates tested were: (1) amino acid mixture (Promega, Inc.), consisting of all 20 amino acids; (2) glucose; (3) rich humic acids mixture (HydroOrganics, Inc.). Each of these substrates represented a carbon group that may be used as a carbon source by soil bacteria (Rinnan and Bååth, 2009). All carbon substrates were added to the EC broth at a concentration of 10 mM carbon-C, then the broth-carbon-isolate tube was placed into a shaking incubator at 37°C for 48 hours.

After 48 hours, an aliquot of microbial growth from each tube was added to a fresh broth-carbon mixture, and this was repeated for a total of 10 growth cycles. After 10 growth cycles, each isolate was tested for sensitivity to the same suite of antibiotics (Table 1). This method, rather than being a “presence/absence” test for antibiotic resistance, allowed resistance trends to be quantified; for example, a bacterium that initially showed high-level resistance to Nitrofurantoin by displaying growth at 128 $\mu\text{g mL}^{-1}$ may be losing resistance after 10 growth cycles, and may not be able to grow beyond 64 $\mu\text{g mL}^{-1}$.

Table 2. Antibiotic resistance patterns of isolates used for re-enrichments. Isolates were archived from 2011 study examining bacteria in feedlot runoff; IDs (column 1) refer to identification given to each bacterium in the earlier research study.

Isolate ID	# Resistance Traits	Resistance Genes
3AA	8	AMP; AMP/SUB; CFZ; CFN; CFX; CFM; NIT; CEF
7CA	4	AMP; AMP/SUB; CFZ; CFX
9CB	4	AMP; AMP/SUB; CFZ; CFX
19AB	4	AMP; CFZ; CFX; CEF
19BB	11	AMP; AZT; CFZ; CFN; CFD; CFX; CFM; PIP; PIP/TAZ; TIC/CLA; CEF
25CA	4	AMP; AMP/SUB; CFZ; CFX
1CB	4	AMP; AMP/SUB; CFZ; TIC/CLA
27CB	4	AMP; AMP/SUB; CFZ; CFM
35AA	4	AMP; CFZ; CFX; CEF
29BA	10	AMP; AZT; CFZ; CFN; CFD; CFX; CFM; PIP; PIP/TAZ; CEF
31BA	11	AMP; AZT; CFZ; CFN; CFD; CFX; CFM; PIP; PIP/TAZ; TIC/CLA; CEF
37AB	10	AMP; AMP/SUB; AZT; CFZ; CFN; CFD; CFX; CFM; PIP/TAZ; CEF

12 isolates with numbers of resistance markers ranging from 4 to 11 (Table 2). After 30 enrichments, bacteria exposed to amino acids showed the largest drop in resistance markers, averaging 2.8 markers per isolate (Figure 1). Markers per isolate in bacteria exposed to glucose and humic acids also dropped, averaging 6.1 and 5.9 markers per isolate, respectively.

Results after 55 enrichments did not show the same pattern. While resistance markers in bacteria exposed to glucose continued a slight downward trend, falling to 5.9 resistance markers per isolate, markers rose between enrichment 30 and 55 for isolates

Principal Findings and Significance.

In the initial proposal, we estimated that we would perform 60-90 re-enrichments of each isolate for each carbon addition, with a complete antibiotic screening performed following each group of 10 successive enrichments. However, the initial screening of 150 isolates and student training required more time than anticipated and thus, we performed only 55 re-enrichments of the 12 total isolates examined in this study. All data reported below apply to the initial resistance findings (without C addition; Table 2); and results after 30 enrichments and after the final enrichment (Figure 1).

Initial screening revealed a total of

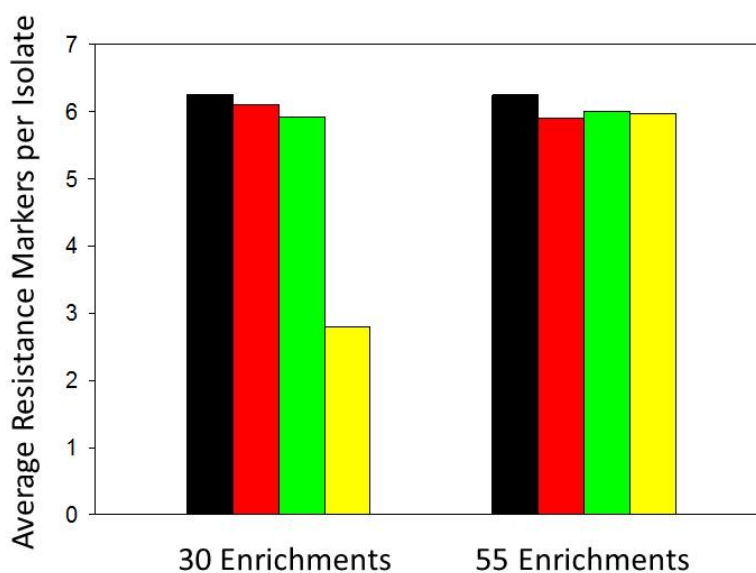


Figure 1. Average resistance markers per isolate after 30 enrichments (left) and 55 enrichments (right) in bacteria with no exposure to carbon substrates (black bars), or exposed to glucose (red bars); humic acids (green bars); or amino acids (yellow bars).

exposed to humic acids (6.0 markers) and amino acids (5.9 markers).

The contribution of agricultural practices, including irrigation with recycled wastewater, to the development of antibiotic resistance has been widely studied. However, the causal relationship between application of trace amounts of antibiotics and the development of resistance is still under debate, with evidence either supporting or declining the contribution of antibiotics to alteration of antibiotic resistance. Several studies have reported that antibiotics do not seem to pose significant effects on the amplification of resistance in soil microbes, especially when applied with a rich carbon substrate (manure) (Sengeløv et al., 2003; Hund-Rinke et al., 2004).

We know of no studies in which carbon impacts on multiple-antibiotic resistance of soil isolates have been studied. Our hypothesis for carbon-induced reductions in resistance to

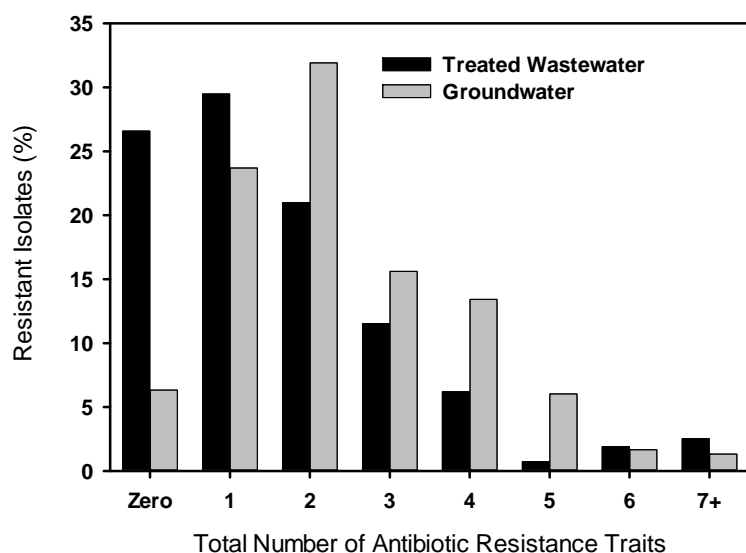


Fig 2. Multiple-antibiotic resistance levels in soil bacteria after 25+ years recharge with recycled wastewater (black) or groundwater (grey). High-levels resistance to multiple (2 or more) antibiotics was identified in more than 70% of isolates exposed to groundwater, but fell to 50% after long-term exposure to recycled water.

multiple antibiotics is based on findings from two preliminary studies, one conducted at a site that has undergone long-term recharge with recycled municipal wastewater (Figure 2), and another at a site following long-term biosolids application. In both sites, multiple antibiotic resistance was far lower in soils exposed to higher carbon. In the biosolids-treated soils, multiple-antibiotic resistance fell as biosolids application levels increased, falling from 45% of isolates in soils receiving 10 dry tons per acre per year (25 years) to 10% of isolates in soils receiving 30 dry tons per acre per year.

These initial, very intriguing findings were the catalyst for the current study. Because multiple-antibiotic resistant organisms are of immense clinical concern, examination of stressors that may reduce resistance would be of immense interest in both the environmental and medical realms.

Although the one-year study revealed trends in decreased multiple-antibiotic resistance in isolates exposed to carbon substrates, it is clear that a far longer laboratory study would be required to achieve resistance reductions of the size observed in environmental bacteria.

Though results of this laboratory study were less than striking, the funds supported the training of University of Arizona senior Elissa Malott, who graduated in December 2013

from the Department of Veterinary Science and Microbiology. Elissa worked part-time (10-15 hrs per week) on the project, performing all sample processing and data collection and analysis. This experience undoubtedly prepared Elissa for research at the graduate level, and in January 2014, she began her Master's level research in the laboratory of Dr. Channah Rock, a co-PI on this project.

References.

- Arizona Department of Environmental Quality (ADEQ). 2003. Arizona Biosolids/Sewage Sludge Management Program, <http://www.azdeq.gov/envIRON/water/permits/download/bioprog.pdf>; Accessed 13 May 2014.
- Arizona Department of Water Resources (ADWR). 2010. Arizona Water Atlas: Volume 1 Executive Summary. Phoenix, Arizona: ADWR, Office of Water Management.
- Baquero F et al. 2008 Antibiotics and antibiotic resistance in water environments. *Current Opinion in Biotechnology*. 19(3), 260–265.
- Cooke MD. 1978. Antibiotic resistance among coliform and fecal coliform bacteria isolated from sewage, seawater, and marine shellfish. *Antimicrobial Agents and Chemotherapy*, 9(6), 879-884.
- Da Costa PM et al. 2008 Antimicrobial resistance in *Escherichia coli* isolated in wastewater and sludge from poultry slaughterhouse wastewater plants. *Journal of Environmental Health*, 70(7), 40–45.
- Halling-Sorensen C et al. 1998. Occurrence, fate and effects of pharmaceutical substances in the environment - a review. *Chemosphere*, 36(2), 357–393.
- Hopwood DA. 2007. How do antibiotic-producing bacteria ensure their self-resistance before antibiotic biosynthesis incapacitates them? *Molecular Microbiology*, 63, 937–940.
- Hund-Rinke K et al. 2004. Effects of tetracycline on the soil microflora: function, diversity, resistance. *Journal of Soils and Sediments*, 4:11–16.
- Kolpin et al. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in US Streams, 1999–2000: a national reconnaissance. *Environmental Science and Technology*, 36(6), 1202–1211.
- Linares JF. 2006. Antibiotics as intermicrobial signaling agents instead of weapons. *Proceedings of the National Academy of Science (USA)*, 103, 19 484–19 489.
- Murray GE et al. 1984 Effect of chlorination on antibiotic resistance profiles of sewage related bacteria. *Applied and Environmental Microbiology*, 48(1), 73–77.
- Quigley T. 2009. Monitoring the Growth of *E. coli* With Light Scattering Using the Synergy™ 4 Multi-Mode Microplate Reader with Hybrid Technology™, BioTek Instruments, Inc., http://www.biotek.com/resources/docs/E_coli_app_note_final_format-2.pdf
- Rinnan R and Bååth E. 2009. Differential utilization of carbon substrates by bacteria and fungi in tundra soil. *Applied and Environmental Microbiology*, 75(11), 3611-3620.

Sengeløv G et al. 2003. Bacterial antibiotic resistance levels in Danish farmland as a result of treatment with pig manure slurry. *Environment International*, 28:587–595.

Tahlan, K. et al. 2007. Initiation of actinorhodin export in *Streptomyces coelicolor*. *Molecular Microbiology*, 63, 951–961.

World Health Organization (WHO). 2000. WHO Annual Report on Infectious Disease: Overcoming Antimicrobial Resistance. World Health Organization: Geneva, Switzerland, www.who.int/infectious-disease-report/2000/. Accessed 12 May 2014.

Yang S and Carlson K. 2003. Evolution of antibiotic occurrence in a river through pristine, urban and agricultural landscapes. *Water Research*, 37(19), 4645–4656.

Discrimination-Inference to Reduce Expected Cost Technique (DIRECT): A new framework for water management and stakeholder negotiation

Basic Information

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Publications

1. Kikuchi, C., T.P.A. Ferré, and J.M. Welker. 2012. Spatially telescoping measurements for improved characterization of groundwater-surface water interactions. Journal of Hydrology, DOI: 10.1016/j.jhydrol.2012.04.002.
2. Kikuchi, C., T.P.A. Ferré, and J.A. Vrugt. A Data Discrimination Index (DDI) for hydrologic monitoring network design, submitted to Water Resources Research.
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4. Kikuchi, C., T.P.A. Ferré, and L. Petersen. Considering data worth and expected value in prioritizing water rights acquisition. In preparation for Journal of Hydrology.
5. Hundt, S. and T.P.A. Ferré. Designing a pump and treat system considering uncertainties in background gradient and costs. In preparation for Journal of Hydrology.

Improving Hydrologic Investigations for Decision Support through Multi-Model Analysis and Discriminatory Data Collection (MMA-DDC)

Final Report, May 2014

Problem Statement and Research Objective

Practicing hydrogeologists are called upon to make specific predictions about future hydrologic conditions that will form the basis for social, economic, and political decisions. The major challenges to accurate hydrologic prediction are: 1) capturing the inherent complexity of hydrogeologic systems in models; 2) acquiring sufficient informative data to characterize the critical hydrologic processes; and 3) providing predictions of interest for decision makers with associated, quantitative uncertainties to allow for robust decision making. Commonly, the modeling and measurement bottlenecks listed as 1 and 2 are seen as two interacting, yet separate, aspects of hydrologic science. We propose a novel approach that combines cutting edge tools in hydrologic modeling with a new approach to monitoring network design that addresses both of these fundamental limitations jointly. Then, we show that this approach can help to provide predictions with quantitative uncertainties that are tailored for specific stakeholder needs. Specifically, we developed a set of tools that allow for multi-model analysis combined with a discriminatory approach to data collection to design more informative hydrogeologic measurement and monitoring networks. Based on our findings, we developed an initial, stand-alone tool that can interface with readily available hydrogeologic software to implement Multi-Model Analysis with Discriminatory Data Collection (MMA-DDC).

Methodology

Under this grant, we initiated the development and application of MMA-DDC to hydrologic investigations by:

- Developing statistically robust theoretical underpinnings for MMA-DDC
- Implementing the computational procedure for MMA-DDC in a modular computer code
- Completing a comprehensive literature review to develop a library of mathematical functions suitable for calculating environmentally- and agriculturally-relevant cost functions
- Applying MMA-DDC analysis to water resources investigations with broad relevance
 - Optimal monitoring network design for vadose zone contaminant transport
 - Monitoring the effects of groundwater conservation in riparian areas

Conceptual underpinnings of MMA-DDC

Conceptual development of hydrologic models entails stating hypotheses about the structure, processes, property values, and boundaries of hydrologic systems based on available

information. These hypotheses are embodied in a set of hydrologic models, each capable of making predictions in both space and time. The structure of MMA-DDC is summarized in figure 1. All available information about boundary and initial conditions, parameter values, and process conceptualization is used to develop an ensemble of plausible models. Each model in the ensemble calculates simulated values \hat{Y} for the hydrologic system of interest. These model-simulated values are first divided into calculations of previous and future states and fluxes. Simulated values at and before the present time, τ , are used to assess the relative likelihoods of the models in the ensemble. Calculated future values ($t > \tau$) are further subdivided. Some of these future calculations are considered for future data collection and are referred to as *candidate measurements*. Other future calculations are used for decision support and are referred to as *predictions of concern*, ξ . Any of these model-simulated values may be processed through secondary models before they are used. For example, calculations of previous states or fluxes at candidate measurement points can be processed using instrument response models for comparison with geophysical measurements (Hinnell et al., 2010).

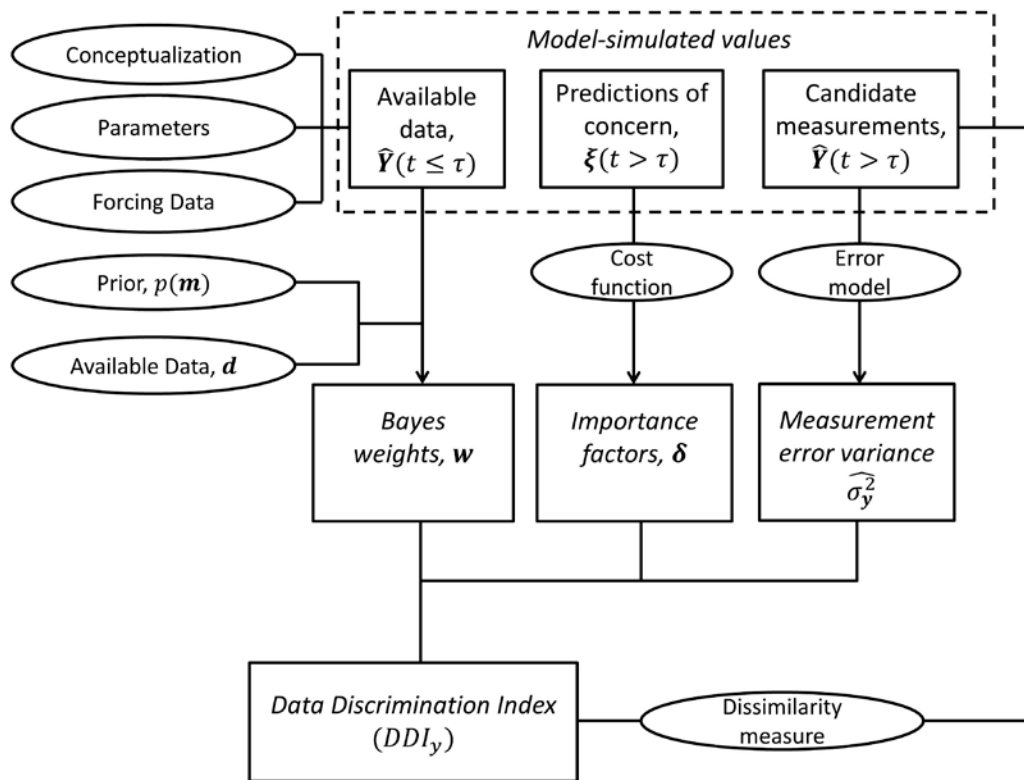


Figure 1. Schematic illustration for calculating the Data Discrimination Index (DDI_y) for a given candidate measurement.

Similarly, calculations of future states and fluxes can be interpreted with secondary models and cost functions to assess environmental impacts and associated costs. As detailed below, MMA-DDC is designed to combine model likelihoods expressed as Bayes weights, model importance

factors calculated with cost functions, and measurement error variance (with consideration of the expected value of the measurement) to prioritize candidate measurements for collection.

Derivation of the Data Discrimination Index

Consider N models developed to explain and make predictions of some hydrologic phenomena. We assume that every effort has been made to consider a broad range of possible model structures, thereby fully capturing the uncertainty in model conceptualization, parameterization, and forcing inputs. We wish to use the ensemble of models to make specific predictions of interest and to prioritize future data collection efforts. We consider M candidate measurements and index them based upon measurement type, location, and time. Each candidate measurement will have a vector of N model-simulated values, one corresponding to each model in the ensemble, and referred to as $\widehat{\mathbf{y}}_j$. In addition to the candidate measurements, we consider C predictions of interest for economic, social, or environmental reasons, $\boldsymbol{\xi}$. These predictions of interest, $\boldsymbol{\xi}$, populate an $N \times C$ matrix of values. Some predictions of interest may be directly useful for decision support; for example, predicted changes in streamflow or drawdown surrounding a well. Other predictions of interest may require additional transformation to be used for decision support; for example, exposure time above a regulatory limit may require analysis of the solute concentration time series and may vary by location and species of interest.

Model likelihoods

We use the relative likelihood assigned to each model to weight corresponding simulated values for the candidate observations. The value for the j th candidate measurement simulated by the k th model m_k , will be referred to as $\widehat{y}_{j,k}$. The observed value for this candidate measurement, if selected, will be referred to as y_j . The uncertainty in $\widehat{\mathbf{y}}_j$ is characterized by the probability density function $g(\widehat{\mathbf{y}}_j)$. An appropriate formulation for $g(\widehat{\mathbf{y}}_j)$ is a marginal distribution, summing over all N models:

$$g(\widehat{\mathbf{y}}_j) = \sum_{k=1}^N p(\widehat{y}_{j,k} | m_k) p(m_k) \quad (1)$$

The product inside the summation in equation (1) is the probability that the simulated value, $\widehat{y}_{j,k}$, of the k th model, is correct. The first term on the right hand side of equation (1) is the conditional probability of the k th simulated value, $\widehat{y}_{j,k}$, given that the k th model is correct. The second term on the right hand side of the equation is the probability that the k th model is correct. In the absence of data, $p(m_k)$ is simply the user-specified prior probability. As data become available, then $p(m_k)$ is calculated as the posterior probability of the k th model using Bayes' law:

$$p(m_k | \mathbf{d}) = \frac{p(\mathbf{d} | m_k) p(m_k)}{p(\mathbf{d})} \quad (2)$$

The terms on the right hand side of equation (2) are $\mathcal{L}(m_k | \mathbf{d}) \equiv p(\mathbf{d} | m_k)$, where $\mathcal{L}(m_k | \mathbf{d})$ is the likelihood, $p(m_k)$ is the prior, $p(\mathbf{d})$ is the evidence, and \mathbf{d} is a vector of existing data. The likelihood and the prior vary across the model ensemble, as discussed below. The evidence

depends only upon the available data and serves as a normalizing constant. Given that we are only considering the relative value of the candidate observations, we can omit $p(\mathbf{d})$ and re-write equation (2) as:

$$p(m_k|\mathbf{d}) \propto p(m_k)\mathcal{L}(m_k|\mathbf{d}) \quad (3)$$

It is difficult to define a formal likelihood function that mimics exactly the residual distribution in the presence of model and forcing data error (Beven, 2006). Therefore, it is commonly assumed that the residuals are independent and follow a Gaussian distribution. We recognize that many formal and informal methods are available for determining Bayes weights; for example, it would also be possible to use different formal likelihood functions accounting for non-Gaussian and correlated error distributions (e.g. Schoups and Vrugt, 2010). Less formal likelihood functions are also possible, and are discussed in more detail by Smith *et. al.* (2008). The general formulation of the Data Discrimination Index (DDI) allows for flexibility in the selection of model likelihood functions.

After evaluating $p(m_k|\mathbf{d})$ using equations (3) and (4), we next use a normalizing procedure to compute the Bayes' weights:

$$w_k = \frac{p(m_k|\mathbf{d})}{\sum_l^N p(m_l|\mathbf{d})} \quad (4)$$

The quantity w_k on the left hand side of equation (4) is the Bayes' weight, and provides a measure of belief in the k^{th} model. The normalization described in equation (4) ensures that w_k sums to one over the model ensemble. We then use the Bayes' weights to evaluate $g(\widehat{\mathbf{y}}_j)$, in equation 1:

$$g(\widehat{\mathbf{y}}_j) = \sum_{k=1}^N w_k p(\widehat{y}_{j,k}|m_k) \quad (5)$$

As formulated above, the ensemble of N models includes only models that differ in their underlying concept and model structure; for example, distribution of geologic units, or selection of important hydrologic processes. For each model, specific predictions vary corresponding to the distribution of model inputs and parameters. In approaches based on either regression or mechanistic models, it is common to use the conditional probability in equation (5) to account for parameter uncertainty. For example, we might consider three conceptual models, each of which has ten parameterization schemes. In this case, the conditional probability would be integrated over all ten possible parameterization schemes for each of the three members in the model ensemble. MMA-DDC takes a different approach to specifying the conditional probability in equation (5). We consider each combination of model conceptualization, parameterization, and forcing inputs as a unique member of the model ensemble, rather than gathering the results by, for instance, underlying conceptual model. We contend that this approach avoids the common confusion of inference and diagnosis of conceptual and parameter uncertainty (Doherty and Christensen, 2011) and allows for a more objective analysis of uncertainties arising from interactions among model inputs, conceptualizations, and parameterizations. With this approach, the total number of simulated values for each candidate measurement is, by definition, equal to

the number of models, N . Therefore, the conditional probability in equation (1) may be written as,

$$p(\widehat{y}_{j,k}|m_k) = 1 \quad (6)$$

By combining equations (5) and (6), we define the probability for a given value $\widehat{y}_{j,k}$ of the j th candidate measurement as the Bayes' weight of the k th model.

The MMA-DDC measurement selection process requires the definition of a Data Discrimination Index (DDI) that quantifies the dissimilarity among the predicted values of candidate measurements among the models in the ensemble. The DDI values are used to rank and select from among the candidate measurements. We represent the dissimilarity of model-simulated values for the j th candidate measurement using the standard deviation as a measure of statistical dispersion:

$$DDI_j = \sigma_{\widehat{y}_j} = \sqrt{\sum_{k=1}^N p(\widehat{y}_{j,k}) (\widehat{y}_{j,k} - \bar{\widehat{y}}_j)^2} \quad (7)$$

where $\widehat{y}_{j,k}$ is the model-simulated value, $p(\widehat{y}_{j,k})$ is the probability associated with simulated value $\widehat{y}_{j,k}$, and $\bar{\widehat{y}}_j$ is the mean value of \widehat{y}_j over all N models in the ensemble. Measures of statistical dispersion other than the standard deviation may also be used at this stage in the analysis with appropriate rewriting of equation (7), if so desired. In the absence of data, $p(\widehat{y}_{j,k})$ is the user-specified prior. If data are available, $p(\widehat{y}_{j,k})$ is set equal to the Bayes weight of the k th model w_k , calculated using the available data. Equation (7) is then evaluated by substituting the summand from the marginal distribution in equation (5) for $p(\widehat{y}_{j,k})$, resulting in:

$$DDI_j = \sqrt{\sum_{k=1}^N [p(\widehat{y}_{j,k}|m_k) w_k (\widehat{y}_{j,k} - \bar{\widehat{y}}_j)^2]} \quad (8)$$

Equation (8) defines the standard deviation of ensemble-simulated values representing the candidate measurement y_j . That is, the Data Discrimination Index for the j th candidate measurement depends upon both the distribution of \mathbf{w} and $\widehat{\mathbf{y}}_j$ over the ensemble. In simpler terms, the DDI allows us to identify the measurements that are most likely to discriminate among the models because the models (weighted by their likelihood based on all existing data) make different predictions regarding what will be measured. As a corollary to this, the DDI would be zero for a given candidate measurement if all of the models in the ensemble predicted the same value of that measurement; that is, making the measurement will make no difference in the relative likelihoods of the models.

2.4 Model importance

Formulating Bayes' weights to determine model likelihoods lays the groundwork for value-of-data analysis in a multiple model context. Measurement selection in MMA-DDC rests on the fundamental premise that measurements performed at times and locations for which model-simulated values are most dissimilar reduces critical uncertainties in hydrologic model predictions, thereby providing data that are best suited for decision support. Stated another way, there is little or no expected value in collecting an observation that is predicted to be very similar by all of the models in the ensemble. As discussed below, we simultaneously consider the importance of models in the ensemble based on the expected value (or cost) of their predictions. In this way, *MMA-DDC is designed to identify the data that are most likely to reduce prediction uncertainties that are most important for decision support.*

For the purposes of management and decision-making, the prediction uncertainties most important for decision support are those that lead to the greatest cost (or lowest value) due to uncertainties in predictions of interest that relate to social, ecological, or economic outcomes. We wish to focus our data collection efforts on acquiring observations that are most like to reduce these critical uncertainties in model predictions. Our approach is based on the standard definition of expected value, or utility, first presented by Daniel Bernoulli (Bernoulli, 1738). This states that the expected value is the sum of the product of the likelihood and cost (or value) of each outcome over all possible outcomes. The models in the ensemble and associated cost models can provide both of these measures, allowing us to calculate the expected cost (or value) for any predicted future condition. Some portion of this expected utility is due to models with relatively low likelihood, but predictions of interest that differ in important ways from the maximum likelihood predictions. Another portion of the expected utility is due to models with predictions of interest that are equal to or only slightly different from the expected value, but that have high likelihoods.

To prioritize both of these cases, we define an importance factor for each model as:

$$\delta_k = \boldsymbol{\omega}^T f(\boldsymbol{\xi}_k) \quad (9)$$

In equation (9), $\boldsymbol{\omega}^T$ is the transpose of a weighting vector used to assign relative importance coefficients to the costs associated with $\boldsymbol{\xi}_k$. Those costs are calculated by the cost function, $f(\cdot)$. The cost function for the k th model depends exclusively upon the predictions of concern, $\boldsymbol{\xi}_k$. We have completed a literature review of cost functions used in agricultural and environmental applications and are currently developing a cost function library. This library, when integrated with MMA-DDC, will provide the user with options for selecting common mathematical forms for economic cost functions. Examples of cost functions are shown in figure 2.

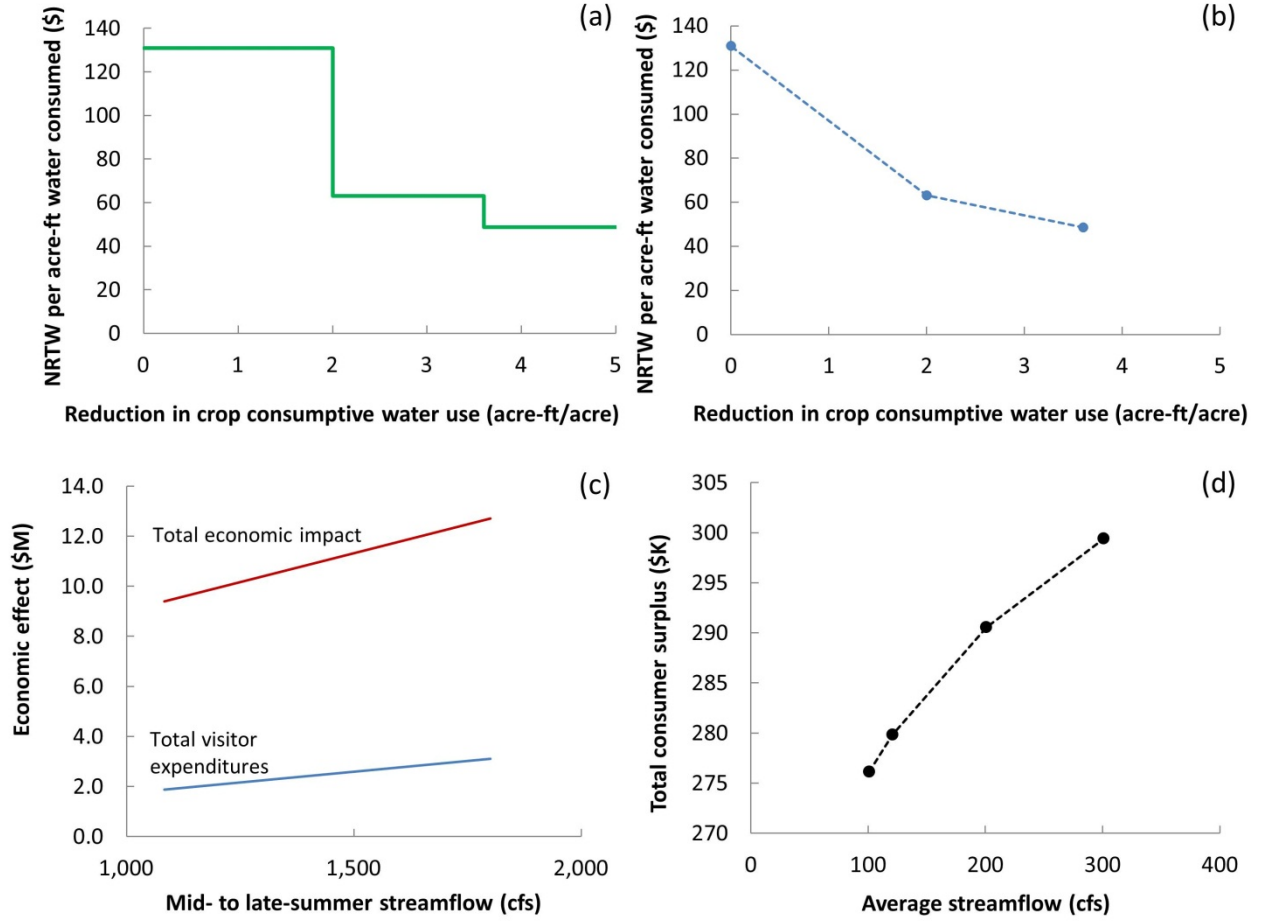


Figure 2. Examples of cost functions suitable for use in DIRECT. Change in Net Returns to Water (NRTW) from (a) substitution of water-efficient crops, and (b) incremental changes in crop acreage and irrigation intensity in the Lower Colorado River Basin. (c) Predicted visitor expenditures and total economic impact at different streamflow levels on the Upper Rio Grande, New Mexico, (d) Total consumer surplus at different streamflow levels on the Feather River, California.

Each model is then weighted by its corresponding importance factor:

$$DDI_j = \left(\overline{\sigma_{\hat{y}_j}^2} \right)^{-1} \sqrt{ \sum_{k=1}^N \left[p(\hat{y}_{j,k} | m_k) w_k \delta_k (\hat{y}_{j,k} - \bar{\hat{y}}_j)^2 \right] } \quad (10)$$

In certain stakeholder negotiation scenarios, it is very difficult to determine objectively the weighting vector ω ; instead, it may be better to consider the different predictions of concern in a multicriteria framework (Hajkowicz and Collins, 2007). To satisfy this concern, the weighting vector ω would be omitted from equation (9), resulting in a vector δ_k containing costs associated with each prediction of concern in ξ_k . After calculating N vectors δ_k , the entries from each δ_k would then be used to compute a set of distinct DDI values for each prediction of concern for each candidate measurement.

2.5 Measurement error

The set of candidate measurements may include multiple measurement types. Therefore, we need to account explicitly for the expected observational error of each measurement to allow for quantitative intercomparison among the candidate observations. It is often assumed that observational error, ε , follows a Gaussian distribution; that is,

$$\varepsilon \sim N(0, \sigma_{y_j}^2) \quad (11)$$

MMA-DDC is not restricted to this assumption; however, for simplicity, we adopt this assumption for the examples presented herein. We further assume that measurement errors are independent. In equation (11), $\sigma_{y_j}^2$ is the measurement error variance, and depends on the nature of errors arising from particular measurement techniques rather than conceptual, parameter, and input uncertainties pertaining to the hydrologic system. The measurement error variance may be either homoscedastic or heteroscedastic. For the heteroscedastic case, the value of $\sigma_{y_j}^2$ depends on the numerical value of the candidate measurement, y_j . In a measurement selection context, $\sigma_{y_j}^2$ is therefore difficult to estimate since the candidate measurement values are, by definition, unknown. It would be possible to estimate $\sigma_{y_j}^2$ using the expected value of y_j if the theoretical distribution on y_j is known; however, this is seldom, if ever, the case. Alternately, we may use the model ensemble to estimate $\sigma_{y_j}^2$ as the expected value of $\sigma_{\hat{y}_j}^2$, using the probability density function $g(\hat{y}_j)$:

$$E[\sigma_{\hat{y}_j}^2] \approx \overline{\sigma_{\hat{y}_j}^2} = \frac{1}{N} \sum_{k=1}^N g(\hat{y}_{j,k}) \sigma_{\hat{y}_{j,k}}^2 \quad (12)$$

Calculating the value of $\sigma_{\hat{y}_{j,k}}^2$ for a given value $\hat{y}_{j,k}$ requires a measurement error model for each candidate measurement. In general, the measurement error model would be expected to differ among measurement types. If the measurement errors are expected to be heteroscedastic, definition of the measurement error variance for a particular candidate measurement using equation (12) requires a probability density function $g(\hat{y}_j)$, and a measurement error model for the candidate measurement. For the more simple homoscedastic case, the measurement error variance would be a user-specified constant. To provide intercomparison among all candidate measurement types, we use the inverse of the estimated measurement error variance, $(\overline{\sigma_{\hat{y}_j}^2})^{-1}$, to weight the DDI:

$$DDI_j = (\overline{\sigma_{\hat{y}_j}^2})^{-1} \sqrt{\sum_{k=1}^N [p(\hat{y}_{j,k}|m_k) w_k (\hat{y}_{j,k} - \bar{y}_j)^2]} \quad (13)$$

The purpose of this weighting is to account for data points that may differ in quality. That is, some candidate measurements are potentially informative, but are less useful due to relatively

high measurement error. This inverse weighting procedure is designed to reduce the credence given to those less useful candidate measurements. Stated another way, we seek to normalize all measurements by their expected noise so that all observations can be compared in a single, unitless objective function in terms of their signal to noise ratio.

The unitless DDI is calculated for each candidate measurement. In this preliminary investigation of MMA-DDC, we examine the simplest procedure: selecting candidate measurements with the highest DDI as the most discriminatory dataset. We further assume that the structure of the data collection efforts (e.g. number of measurements at each measurement time) is constrained. For cases in which few proposed observations are available, it is possible to perform this selection by inspection. If there are many proposed measurements encompassing significant variability in the location, timing and measurement type, then optimization is required to identify the most discriminatory dataset.

2.6 User friendly tools

The underlying models that comprise MMA-DDC are relatively complicated to understand and to use properly. But, the ultimate goal of developing MMA-DDC is to produce a tool that can bridge the communication gap between scientists and decision makers. For this reason, we have also put effort into developing prototype GUI's to allow for simple applications of MMA-DDC. Two examples are presented here with descriptive captions.

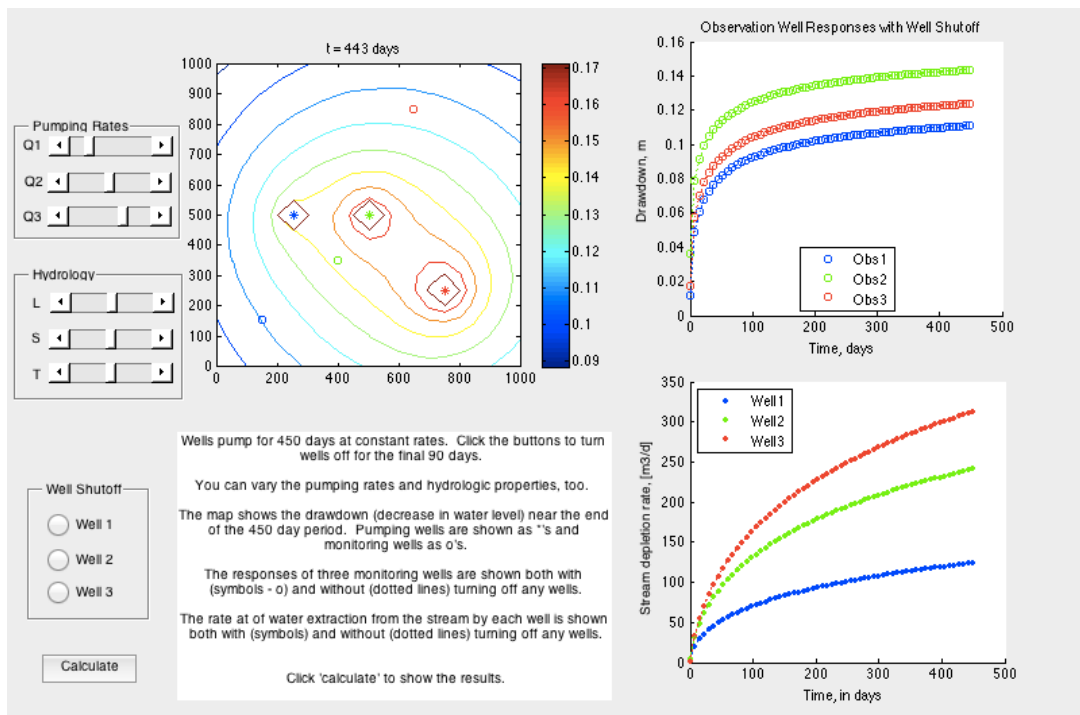


Figure 3. Screen shot of a GUI that employs the principals of MMA-DDC to visualize the impacts of taking a well out of service on capture from a nearby stream. The text guides a user through changing the hydrologic properties and the pumping rates of three wells. The graphs and plots show the relationship between the prediction of interest (capture) and the responses of candidate wells.

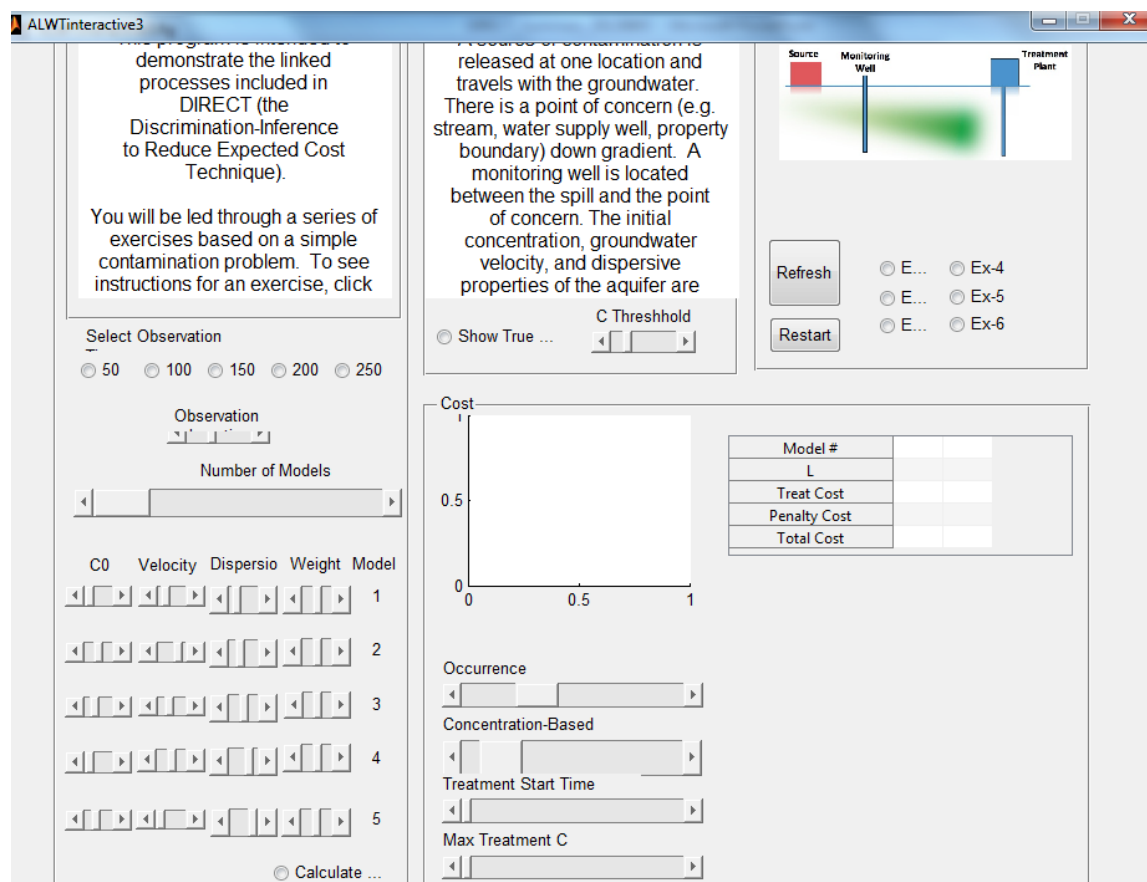


Figure 4. Screen shot of a GUI that employs the explains the application of MMA-DDC. Users are guided through a series of exercises. They choose observation wells and then fit models to their data. They are taught how to develop multiple competing models and how to use them to make likelihood weighted predictions. Finally, they can define a cost function and use the predictions to design a treatment facility. All instructions are included in the GUI so that it can be run as a stand-alone app.

Principal Findings and Significance

MMA-DDC represents a new approach to designing hydrologic investigations to best support decision making under uncertainty. There have been other efforts to identify data that are best able to test hydrologic conceptual models or to improve parameter estimation. But, to our knowledge, MMA-DDC is unique in its combination of measurement selection and importance based on user-defined costs or priorities. While it is a relatively simple matter to develop qualitative predictions about the relative value of future measurements, it is considerably more difficult to produce quantitative measures of prediction uncertainty. These quantitative prediction uncertainties are critical for making decisions based on expected value and for identifying discriminatory data. Therefore, most of our effort during this project has been devoted to developing a solid theoretical and mathematical basis for the Data Discrimination Index that underlies MMA-DDC. We have now completed this step and have developed a modular code based on this foundation. We have applied this code to academic studies regarding

the optimal design of large-scale vadose zone field studies. We have also applied this code to practical studies in support of water-rights acquisition for baseflow augmentation. Finally, we have applied this approach in support of the selection of monitoring points to determine whether to pursue active or passive treatment of a contaminant plume. All of these applications will be the subject of future publications and will acknowledge the support of the 104b program. In addition, we have reviewed and summarized previously published cost functions with relevance to environmental and agricultural problems. These cost functions will be included in the MMA-DDC code as it continues to develop. We believe that MMA-DDC will be an important tool for decision support. Importantly, it will allow decision makers and stakeholders to have quantitative input into the design of hydrologic investigations. It will allow different stakeholders to identify areas of common concern and common priority for data collection. It will allow decision makers and stakeholders to put a monetary value on future data collection. Finally, it will provide a platform for scientifically-based discussions of the role of hydrology to achieve more robust decision making under uncertain conditions.

References

- Bernoulli, D., 1783, *trans.* Somner, L., 1954, Exposition of a New Theory on the Measurement of Risk, *Econometrica*, 22, p. 22-36. Doi:10.2307/1909829.
- Beven, K.J. (2006), A manifesto for the equifinality thesis, *J. Hydrol.*, 320(1-2), 18-36.
- Doherty, J., and Christensen, S. (2011), Use of paired simple and complex models to reduce predictive bias and quantify uncertainty, *Water Resour. Res.*, 47, W12534, doi:10.1029/2011WR010763
- Hajkowicz, S., and Collins, K. (2007), A Review of Multiple Criteria Analysis for Water Resource Planning and Management, *Water Resour. Manage.*, 21, pp. 1553 – 1566.
- Hinnell, A.C., T.P.A. Ferré, J.A. Vrugt, S. Moysey, S.A. Huisman, and M.B. Kowalsky. 2010. Improved extraction of hydrologic information from geophysical data through coupled hydrogeophysical inversion. *Water Resources Research*, 46, DOI 10.1029/2008WR007060
- Schoups, G., and Vrugt, J.A. (2010), A formal likelihood function for parameter and predictive inference of hydrologic models with correlated, heteroscedastic, and non-Gaussian errors. *Water. Resour. Res.*, 46, W10531, doi: 10.1029/2009WR008933
- Smith, P., Beven, K., Tawn, J. (2008). Informal likelihood measures in model assessment: Theoretic development and investigation. *Adv. Wat. Resour.* 31, pp. 1087-1100.

Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater

Basic Information

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Principal Investigators:	Eduardo Saez, David Matson Quanrud

Publications

There are no publications.

**Sequential advanced oxidation and soil-aquifer treatment for management of trace
organics in treated wastewater
Final Report**

A. Eduardo Sáez, David Quanrud, Robert G. Arnold

a. PROBLEM AND RESEARCH OBJECTIVES

Wastewater reclamation is one of the most important potential methods to preserve water resources, especially in arid and semi-arid regions such as the US Southwest. An increasing number of cities are considering, or have implemented, indirect potable reuse (IPR) projects. In Arizona, the need to reuse water has become greatly exacerbated by drought in the Colorado River system. In particular, wastewater treatment plants in most of Southern Arizona, including the cities of Tucson and Green Valley, must utilize aquifer recharge, since natural water bodies are absent. There is increasing awareness that current wastewater treatment technologies are incapable of removing certain organic chemicals from wastewater that have potential consequences for ecological systems and human health. An option to remove these chemicals of emerging concern (CECs) is the use of tertiary wastewater treatment technologies. Oxidation-based technologies (ozonation and hydrogen peroxide photolysis) have been demonstrated to remove a large number of CECs in potential reuse waters but lingering questions remain as to the potential toxicity of transformation products and the persistence of chemicals resilient to oxidation. In addition, soil infiltration of wastewater effluent is capable of removing CECs before water reaches the aquifer by means of adsorption and biochemical transformations.

Total water demand in the Tucson Active Management Area (TAMA) is about 400,000 acre-feet per year (AFY). An acre-foot is slightly more than 326,000 gallons, so that water demand in the TAMA is about 0.13 trillion gallons per year. Every year, residents of the TAMA utilize about one-half of a cubic kilometer of water to satisfy their municipal, agricultural and industrial needs.

Absent the development of a major new source, water resources sustainability in southern Arizona is entirely dependent on (i) full utilization of the regional entitlement to Central Arizona Project (CAP) water and (ii) expanded use of reclaimed municipal wastewater. About 60 percent of water demand in the TAMA is satisfied by Colorado River water. The long-term security of that supply, however, is threatened by potential over-allocation among signatories to the Colorado River Compact and Mexico, so that future reductions in Arizona's entitlement to that resource are likely. Less than 20 percent of the regional requirement for water is provided by rainfall and natural recharge, so that 20-25 percent of the total demand for water in the TAMA must be satisfied by water reuse. That level of water reuse is already practiced through a combination of (i) planned water reclamation for use in landscape irrigation and (ii) inadvertent or unplanned infiltration of treated wastewater, primarily in the lower Santa Cruz River bed, for aquifer replenishment. Each year more than 40,000 acre feet of treated wastewater is discharged to the lower Santa Cruz River, which is effluent dependent (contains only treated wastewater) for about eleven months of each year.

Tucson's water future and the futures of other southwestern communities that must rely on water resources of impaired initial quality to balance supply and demand are threatened by at least two water quality issues. First, Colorado River water destined to be consumed in the TAMA brings about 200,000 metric tons of salt into the region each year, essentially none of which leaves the

watershed. It is estimated that, on average, the total dissolved solids concentration in accessible ground water in the TAMA increases at a rate of 5 mg/L·yr as a consequence of Colorado River water use. This may lead to long term salt management issues. The second problem motivates research that is proposed here. Conventionally treated municipal wastewater contains an assortment of pharmaceuticals and personal care products (PPCPs) along with a myriad of other trace organic contaminants (TOrcs) at sub-part-per-billion levels that are sometimes poorly attenuated during wastewater treatment (Ahel et al., 1994; Baronti et al. 2000; Kolpin et al., 2002; Birkett and Lester 2003; Drewes et al., 2005; Gulkowska et al., 2008; Stasinakis et al., 2008; Wang et al. 2008; Radjenovic et al., 2009). A subset, the endocrine disrupting compounds (EDCs), is responsible for widely acknowledged environmental impacts (Jobling et al., 1998; Harries et al., 1997; Jobling et al., 1998; Kidd et al., 2006; Vajda et al., 2008), and there has been speculation that chronic exposure among humans to EDCs is associated with elevated incidences of attention deficit disorder, asthma and diabetes. The acceptable uses for reclaimed wastewater, including direct potable reuse, and the methods necessary to ensure public safety as water reuse expands are subjects of public and professional discussion. In few places in the United States is that discussion more relevant to water sustainability than in Tucson.

In a 2002 nationwide survey, the USGS measured some of the highest in-stream concentrations of EDCs in the effluent-dependent lower Santa Cruz River (SCR) near Tucson. Targeted testing by the City of Tucson during 2009 and 2010 under their Microconstituent Sentinel Program detected the compounds perfluorooctane sulfonate (PFOS), carbamazepine, and sulfamethoxazole in three groundwater production wells located along the lower SCR (15-20 mi downstream from wastewater effluent outfalls), suggesting that extracted ground water may include a component of effluent origin. Clearly, concern is warranted regarding the presence and fate of CECs in the Lower SCR watershed.

Tucson provides an exceptional setting in which to study methods for managing the levels of trace organics in reclaimed waters that are destined for potable reuse. It is held that the most cost effective means for ensuring that public safety objectives are met when potable water reuse is inevitable involves a combination of engineered advanced wastewater treatment that is supplemented with natural attenuation processes—during either in-stream transport or infiltration for groundwater replenishment (Quanrud et al., 1996a,b, 2003, 2004). Such schemes tend to minimize economic cost, provide a series of barriers to attenuate trace organics and store water for an extended period awaiting reuse during which potential water quality problems can be detected and avoided. There has, however, been relatively little research with which to evaluate interactions between specific engineered processes and natural attenuation mechanisms in terms of overall reduction to either specific TOrcs or the biochemical properties of treatment residuals.

To better understand CEC loadings to the effluent-dependent lower SCR in Tucson, a 2011 investigation surveyed the presence and fate of a suite of 13 representative CECs during river transport along a 22-mile reach of the lower SCR. A series of groundwater monitor wells located along that same reach was also sampled to assess CECs fate following riverbed infiltration/percolation of effluent. While that study provided substantial new information on transport and fate of selected emerging organic contaminants in the Lower SCR Watershed, it was limited to examining only liquid-phase CECs concentrations and did not assess toxicity or endocrine disruption activity. Many CECs have moderate to high hydrophobicity (high log K_{ow} values) and tend to partition to the solid-phase. Suspended solids in effluent discharged to the SCR are thus a potentially significant additional source of hydrophobic CECs to the Santa Cruz

watershed that were not accounted for in previous investigations. CECs may accumulate in riverbed sediments due to deposition of suspended solids as well as by sorption during effluent infiltration/percolation in the riverbed.

The ecological impact of current CECs loading to sediment in the SCR is unknown but it is reasonable to postulate that benthic organisms uptake CECs and that at least some compounds are biomagnified up the food chain. With the expectation of improved river water quality after completion of SCR wastewater treatment plant upgrades in 2015, reestablishment of fish populations, as has already occurred downstream of the newly upgraded Nogales International Wastewater Treatment Plant located on the Upper SCR, may in fact facilitate a greater biomagnification of some CECs to newly re-established aquatic organism populations and higher-level predators (e.g. fish-eating birds and/or mammals).

In a previous project, we assessed endocrine disruption activities in liquid-phase wastewater effluent, suspended solids, and riverbed sediments as a function of downstream travel distance. A combination of bioassays was used to assess estrogenic and androgenic activities: the Yeast Estrogen Screen (YES) and Yeast Androgen Screen (YAS) reporter gene assays. We evaluated the occurrence and fate of EDCs, measured as estrogenic activity, along a 23-mile reach of the Lower Santa Cruz River (SCR) as a function of distance downstream from municipal wastewater reclamation facilities in Tucson. River water, suspended solids, and riverbed sediments were sampled to establish the persistence of toxicity in river/sediments. Sampling was performed before and after the 2012 summer monsoon rainstorm season to assess associated impacts on sediment-bound endocrine disruption activities as consequence of increased river flow rates during summer runoff events. Liquid-phase and suspended solid concentrations of estrogenic activity decreased by more than 95% during in-stream transport along the 23-mile reach of the SCR. Estrogenic activity concentrations in near-surface sediments were found to be highest in the pre-monsoon riverbed samples. Presumably, these sediments were scoured and transported downstream during high runoff events in summer, replaced by newly deposited (upstream) sediments possessing little or no estrogenic activity. This would thus represent an annual cycle of scour of “contaminated” sediment followed by deposition of relatively cleaner sediment in the riverbed along the effluent-dependent study reach.

The original objective of this project was to examine potential synergy between advanced oxidation (UV/peroxide) and simulated soil-aquifer treatment (SAT) for removal of a representative suite of TORCs that routinely survive conventional wastewater treatment. Advanced oxidation includes a variety of engineered processes that have in common the ability to generate hydroxyl radicals that indiscriminately oxidize reduced chemical targets, including the vast majority of trace organic contaminants in treated wastewater. SAT encompasses processes such as sorption and biochemical transformation that result in contaminant attenuation during the infiltration and underground storage/transport of treated wastewater. Our main hypothesis is that advanced oxidation will transform a number of otherwise persistent contaminants into forms that are more readily attacked by processes that contribute to SAT. Furthermore, the combination of engineered and natural processes is likely to provide water quality benefits for protection of human and environmental health at a cost that is much lower than engineered processes alone.

The current program of study was designed to determine the effects of advanced oxidation processes (AOP) and simulated soil aquifer treatment (SAT), alone and in combination, on the

removal of trace organic contaminants from conventionally treated municipal wastewater (secondary effluent). Experiments were performed at laboratory scale using effluent from the Tres Rios Wastewater Reclamation Facility in Tucson, AZ. Advanced oxidation was provided in the form of UV/hydrogen peroxide treatment using a continuous reactor.

b. METHODOLOGY

Laboratory-scale SAT

Two 122-cm stainless-steel columns, inside diameter (ID) 6.9 cm, were constructed for soil aquifer treatment (SAT) simulations (Figure 1). Threaded ports were located at 6, 12.5, 42.5, 52.5, 72.5 and 86.5 cm below the soil surface for pressure measurements using tensiometers. These consisted of porous sintered stainless-steel cups with 2.0- μm pore size, which were positioned in the center of the columns at each of the six ports. Paraflex plastic tubing (outside diameter 0.64 cm) was connected to each port and filled with tap water for measurements of matric potential (Fig. 1), which was recorded once a day. Columns were packed with surface soil from the Sweetwater Recharge Facilities in Tucson. A gravel (0.47 cm diameter) layer 6-cm depth was used to cover the bottom of each column. The soil (0.5 porosity) was weighed out into Ziploc bags at a mass to reach a bulk density of 1.4 g/cm³ in 10 cm increments. Bags of soil were then added to the columns as a port for a tensiometer was approached and compacted to 10 cm until an 87-cm soil bed was reached.

The two columns have been operated in continuous wet/dry cycles, simulating recharge operations during SAT. During the acclimation period, wet/dry cycles consisted of at least 3 days of continuous pumping of secondary effluent from the Roger Road Wastewater Treatment Facility and the Tres Rios Wastewater Reclamation Facility through the top of each column followed by 3 days of drying. This procedure was continued for 19 cycles. After cycle number 20, wet/dry cycles were set from 7 days of continuous secondary effluent application followed by 4 days of drying. The soil surface was not disturbed and air exchange was allowed to occur during dry cycles.

A single peristaltic pump with two pump heads was used to provide water effluent at equal rates to both columns operated in parallel (Figure 2). For each column, a supply of effluent sufficient for wet cycle continuous operation was maintained in a 20-L container in the dark at 4 °C. Glass tubing wrapped with aluminum foil was used in order to minimize changes in wastewater quality while it was pumped to the columns. Samples of column effluent were obtained from the outlet of each column. UV-254 was measured twice daily (every 12 h) during wet cycles. At the beginning of each wet cycle, sample collection started after 2 h of operation, thus allowing for stable operation of columns. TOC was measured for some of the wet cycles after 48 and 72 h of the beginning of wet cycles. The wastewater infiltration rate through both columns was determined by measuring the volume effluent collected during 1 h twice daily. Excitation-emission matrix (EEM) fluorescence spectroscopy analysis for natural organic matter characterization was also performed for some of the wet cycles.

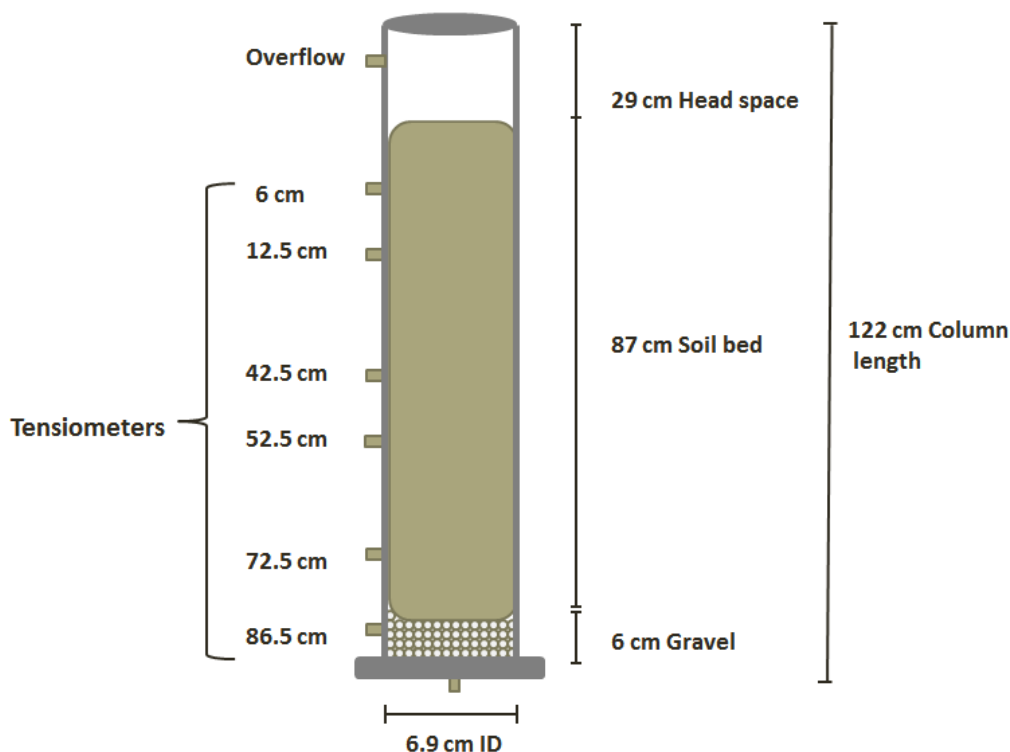


Figure 1. Schematic representation of SAT column layout.

Advanced Oxidation

A pilot-scale UV/peroxide reactor was used to perform UV/hydrogen peroxide experiments (Figure 3). The reactor consists of a 15-cm ID, 1.5-m long stainless steel cylinder that is equipped with a medium pressure 2.5-kW lamp (xenon/mercury with a wavelength-dependent intensity) located concentrically in the barrel. The total available volume of the annular region is 20 L. The reactor is equipped with a quartz sleeve to protect the lamp from flowing water and to remove light energy in the range $\lambda < 220$ nm.

Water flow to the reactor was provided by a variable speed pump (*Dayton Model 1F976*) with a maximum flow of 23 L/min. The medium pressure lamp in the reactor releases considerable heat, so that a minimum flow is necessary to maintain reactor temperature in the range 18-25 °C.

Experiments were performed with secondary effluent from the Tres Rios Wastewater Reclamation Facility in Tucson. TOC, UV-254 and fluorescence excitation-emission matrices were used to quantify TOC removal.

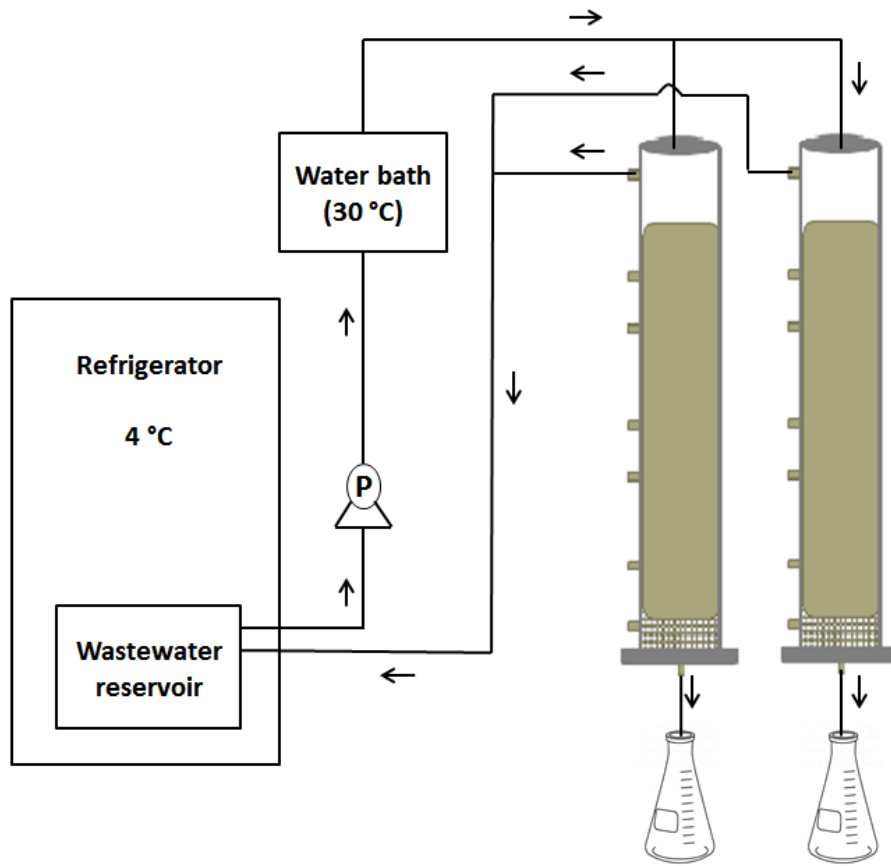


Figure 2. Schematic Representation of SAT experimental setup.

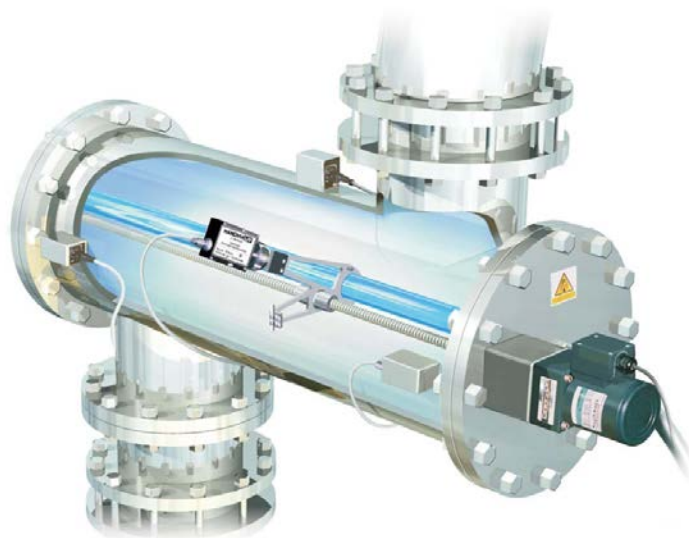


Figure 3. Pilot-scale polychromatic reactor. The medium pressure lamp (2.5 kW) concentrically located at the center of the pipe provides light energy in the UV-visible range.

c. PRINCIPAL FINDINGS AND SIGNIFICANCE

SAT Treatment

The SAT columns were initially operated using secondary effluent from the Roger Road Wastewater Treatment Facility (RRWTF). Variations in the infiltration rate during the first 11 cycles (Figure 4) indicated that the column had not reached a steady state hydraulic regime. It was thought that day-to-day temperature variations in the influent were a probable cause for this. After cycle 11, influent temperature was controlled at 30 °C while at the same time, the column outlets were redesigned to avoid pooling of liquid. After these changes, the infiltration rate dropped considerably and seemed to be steady. However, during cycle 15, the RRWTF was shut down and secondary effluent from that plant became unavailable. At this point, the influent was switched to secondary influent from the Tres Rios Wastewater Reclamation Facility, which has a much lower TOC than the effluent from the RRWTF. As seen in Figure 4, the infiltration rate became unsteady after this change.

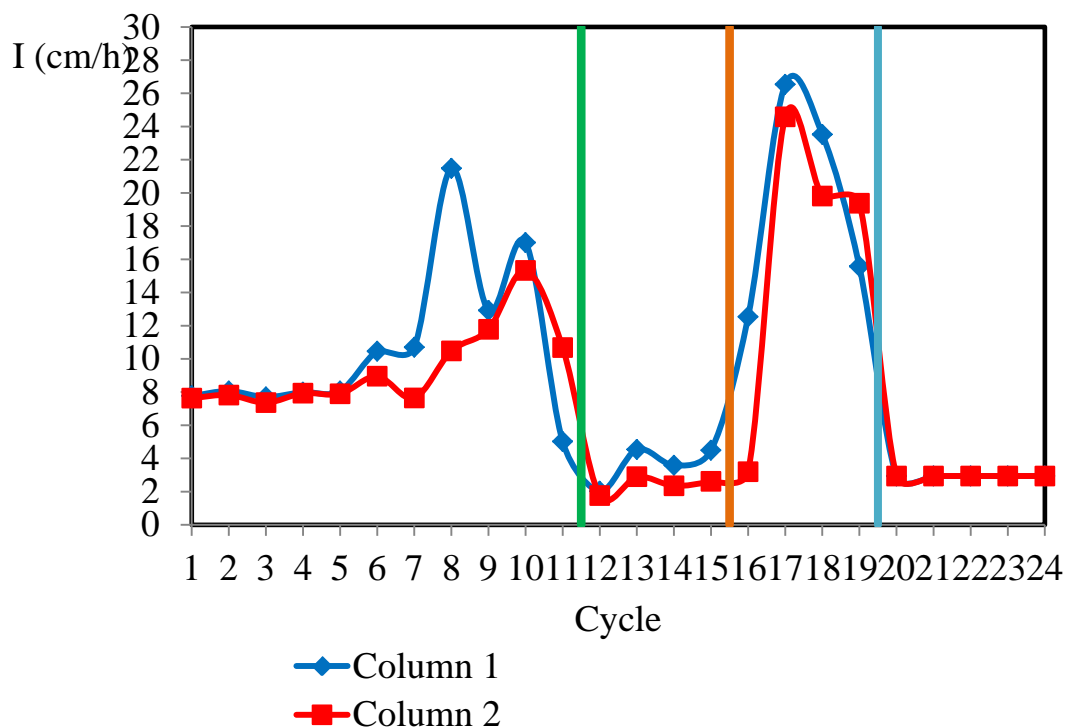


Figure 4. Infiltration rate (I) expressed as superficial velocity as a function of time for the two SAT columns. Cycles 1-19 consisted of three days of continuous flow followed by three days of dry operation. Cycles 20-24 consisted of 7 days of continuous flow followed by four days of dry operation. After cycle number 11, the influent temperature was controlled at 30 °C. Cycles 1-15 employed secondary effluent from the Roger Road Wastewater Treatment Facility. Use of secondary effluent from the Tres Rios Wastewater Reclamation Facility started after cycle 15. Infiltration rate control was started after cycle 19.

To stabilize the infiltration rate, we started controlling the water flow rate through the columns after cycle 19, as shown in Figure 1. However, during the first 24 cycles, influent to effluent

changes in UV 254 nm absorbance (Figure 5), as well as TOC (Table 1) indicated that there was no appreciable removal of organics in the columns. We believe that the organics provided by the Tres Rios Wastewater Reclamation Facility secondary effluent are not able to sustain a microorganism flora that can degrade a substantial portion of the organic matter in the wastewater effluent. Strategies undertaken to mitigate this problem are discussed below.

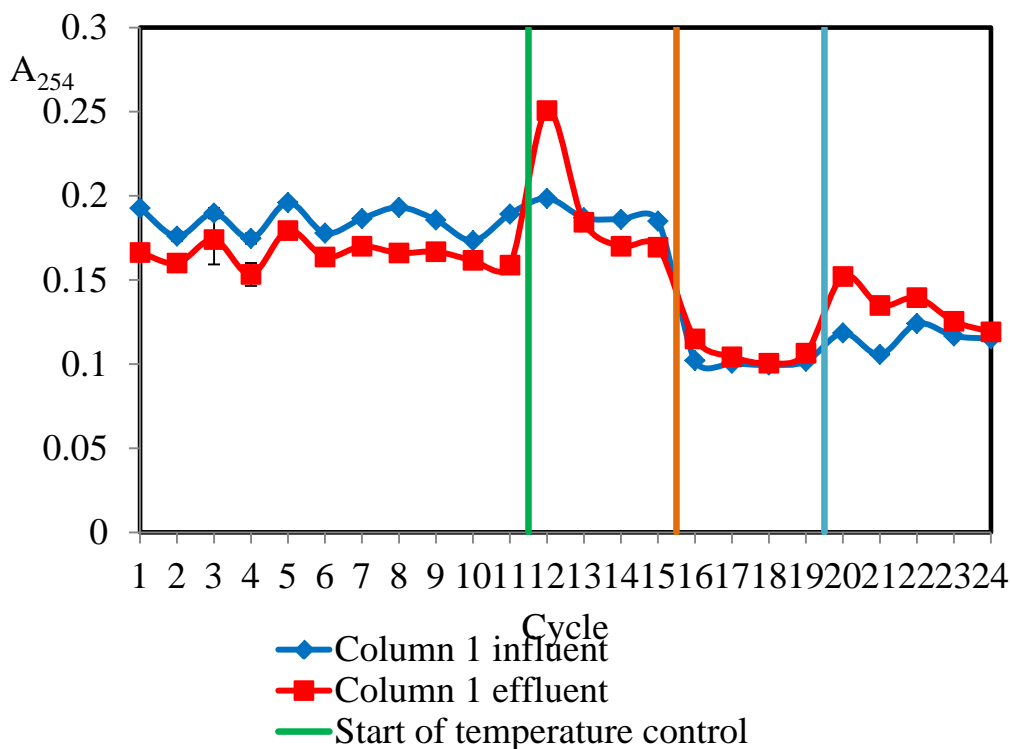


Figure 5. Total absorbance at a wavelength of 254 nm (A_{254} , arbitrary units) as a function of time for Column 1 during SAT experiments.

Table 1. TOC (mg/L) analysis of column influent and effluent during SAT experiments. Specified times represent times from the beginning of the cycle.

Cycle	Column 1 inlet	Column 1 outlet		Column 2 Inlet	Column 2 outlet	
		48 h	72 h		48 h	72 h
8	7.93	5.30	-	7.93	4.70	-
9	8.11	6.13	-	8.11	5.94	-
12	8.52	9.33	-	8.52	8.69	-
15	8.65	5.40	5.76	8.65	7.21	7.10
16	2.87	3.40	3.32	2.87	5.52	5.35
17	4.96	6.09	7.02	4.96	5.88	4.66
18	5.05	4.53	4.97	5.05	4.62	4.87
19	5.70	7.49	6.66	5.70	5.02	5.26
22	5.05	-	4.98	5.05	-	5.01

AOP Treatment

The degradation of TOrCs in wastewater during AOP experiments was studied in terms of the variations of concentrations of humic and fulvic substances, quantified by means of fluorescence spectrometry. Figure 6 shows the excitation/emission matrix (EEM) fluorescence contours for wastewater effluent from the Tres Rios Wastewater Reclamation Facility, identifying the humic and fulvic regions. Treatment of the wastewater in the AOP reactor led to variable attenuation of the fulvic and humic signatures, depending on the H_2O_2 concentration employed. Two example results are shown in Figure 7. In this process, hydrogen peroxide undergoes photolysis, mainly due to the UV part of the lamp spectrum, to produce hydroxyl radicals, which are among the best oxidants known. The hydroxyl radicals oxidize organic compounds in reactions that may produce organics of lower molecular weight or even complete mineralization of the organics to carbon dioxide (Rojas et al., 2010). Comparison of Figures 6 and 7 shows that relatively low concentration of hydrogen peroxide leads to substantial degradation of humic and fulvic substances. These results are better seen in Figure 8 where the ratio of reactor effluent-to-influent concentration is shown as a function of hydrogen peroxide dose.

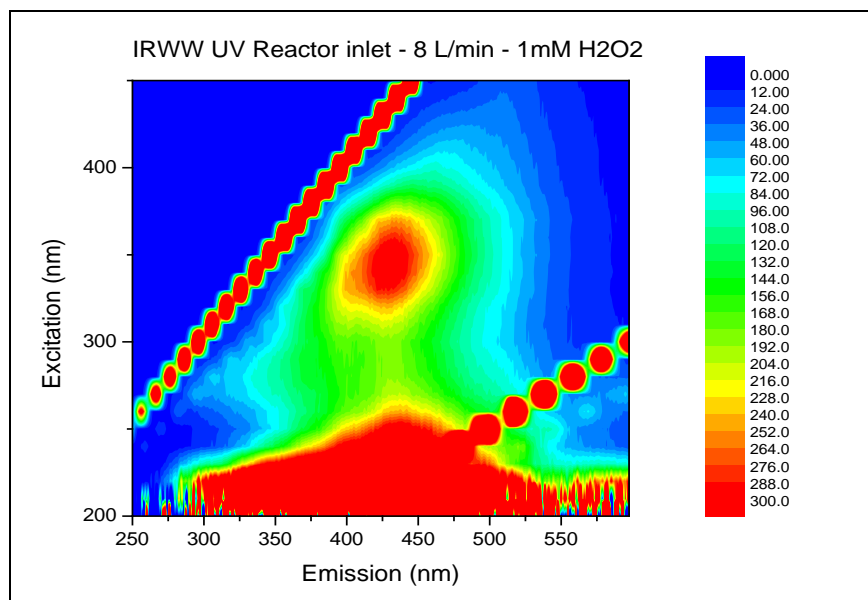


Figure 6. Excitation/emission fluorescence contours of secondary effluent from the Tres Rios Water Reclamation Facility before AOP treatment.

Despite the effectiveness of the AOP process to remove complex organics, as represented by fulvic and humic substances, total organic carbon (TOC) concentration did not change appreciably during the process (Figure 9). This result indicates that complex TOrCs are being degraded into lower molecular weight substances and, therefore, are not being completely oxidized to carbon dioxide. We propose that it would be worthwhile to investigate if this new suite of organics produced after TOrC degradation are adequate as nutrients to sustain microorganisms during SAT treatment.

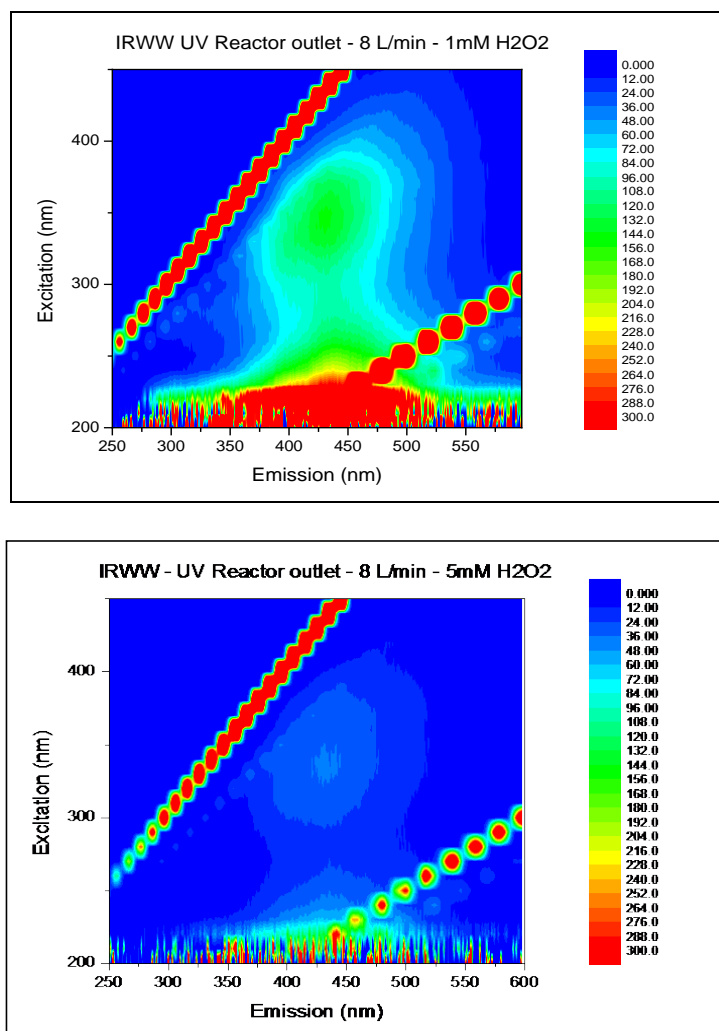


Figure 7. Excitation/emission fluorescence contours of secondary effluent from the Tres Rios Water Reclamation Facility after AOP treatment at the specified H_2O_2 concentrations.

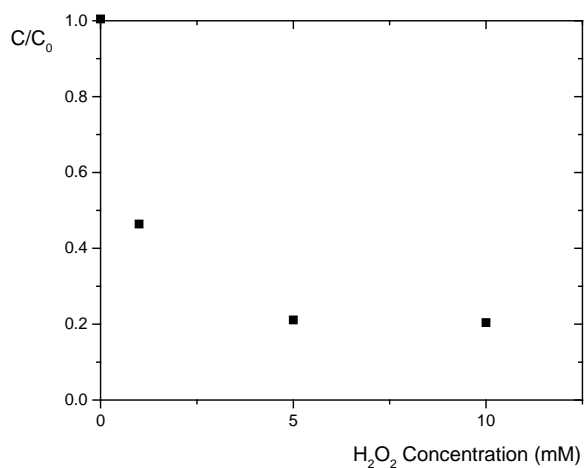


Figure 8. Ratio of reactor outlet to inlet concentrations of humics in secondary effluent from the Tres Rios Water Reclamation Facility after AOP treatment as a function of H_2O_2 concentration.

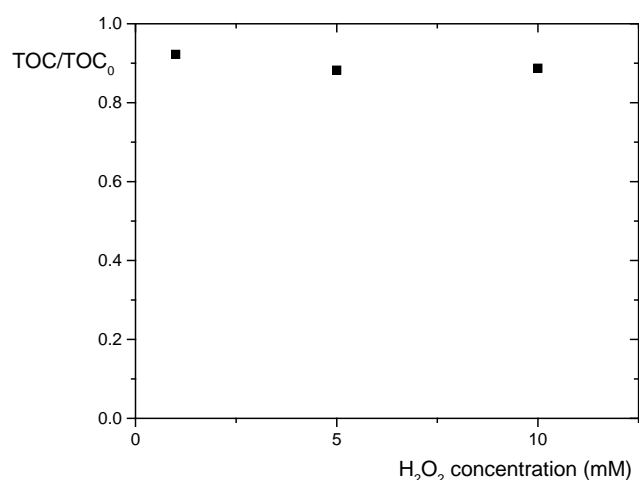


Figure 9. Ratio of reactor outlet to inlet TOC in secondary effluent from the Tres Rios Water Reclamation Facility after AOP treatment as a function of H₂O₂ concentration.

Conclusion

The SAT experiments performed in this work indicated that SAT alone is not an adequate option to remove TOrCs from wastewater effluent. We believe that this is due to the fact that the trace organics present in the Tres Rios effluent cannot sustain a microorganism flora in the soil. On the other hand, advanced oxidation can efficiently remove TOrCs and, therefore, can be used as a standalone remediation method. However, since AOPs are generally expensive, the potential of SAT as a remediation technique should be further explored. We hypothesize that partial oxidation of wastewater effluent using AOPs, which requires a low dose of hydrogen peroxide, can provide a suite of organics that would sustain microorganisms and thus would potentially lead to use of SAT as a treatment technology. The sequence AOP/SAT would then be recommended as the optimum treatment option. We are currently investigating this hypothesis.

References

- Ahel, M., Giger, W., & Schaffner, C. 1994. Behaviour of alkylphenol polyethoxylate surfactants in the aquatic environment—II. Occurrence and transformation in rivers. *Water Research*. 28: 1143–1152.
- Baronti, R. Curini and G. D' Ascenzo. 2000. Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and in a receiving river water. *Environmental Science and Technology*. 34: 5059–5066.
- Birkett, J.W., and Lester, J.N. 2003. Endocrine disrupters in wastewater and sludge treatment processes. Lewis Publishers/CRC Press. Boca Raton, FL. 295p.
- Drewes, J.E., Hemming, J. et al. 2005. An Assessment of Endocrine Disrupting Activity Changes during Wastewater Treatment through the Use of Bioassays and Chemical Measurements. *Water Environment Research*. 77(1): 12-23.
- Gulkowska, A., H. W. Leung, et al. 2008. Removal of antibiotics from wastewater by sewage treatment facilities in Hong Kong and Shenzhen, China. *Water Research* 42(1-2): 395-403.

- Harries, J. E.; Sheahan, D. A.; et al. 1997. Estrogenic activity in five United Kingdom rivers detected by vitellogenesis in caged male trout. *Environmental Toxicology and Chemistry*. 16: 534–542
- Jobling, S., Nolan, M. Tyler, C.R., Brighty, G., Sumpter, J.P. 1998. Widespread sexual disruption in wild fish. *Environmental Science and Technology*. 32(17): 2498-2506.
- Kidd, K.A., P.J. Planchfield, et al. 2007. Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences*. 104:8897-8901.
- Kolpin, D. W. et al. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in us streams, 1999-2000: A national reconnaissance. *Environmental Science & Technology*, 36(6):1202-1211.
- Quanrud, D.M., Quast, K., Conroy, O., Karpiscak, M.M., Lansey, K.E., Ela, W., and Arnold, R.G. 2004. Measurement of estrogenic activity and volume contribution of treated wastewater in water from wells along the Santa Cruz River, Arizona. *Ground Water Monitoring and Remediation*. 24(2):86-93.
- Quanrud, D.M., Carroll, S., Gerba, C.P., and Arnold, R.G. 2003. Virus removal during simulated soil aquifer treatment. *Water Research*. 37(4):753-762.
- Quanrud, D.M., R.G. Arnold, L.G. Wilson and M.H. Conklin. 1996a. Effect of soil type on water quality improvement during soil aquifer treatment. *Water Science & Technology*. 33(10-11) 419-431.
- Quanrud, D.M., R.G. Arnold, L.G. Wilson, H.J. Gordon, D.W. Graham and G.L. Amy. 1996b. Fate of organics during column studies of soil aquifer treatment. *Journal of Environmental Engineering*. 122(4), 314-321.
- Radjenovic, J., M. Petrovic, et al. 2009. Fate and distribution of pharmaceuticals in wastewater and sewage sludge of the conventional activated sludge (CAS) and advanced membrane bioreactor (MBR) treatment. *Water Research* 43(3): 831-841.
- Rojas, M.R., F. Pérez, D. Whitley, R.G. Arnold and A.E. Sáez. 2010. Modeling of Advanced Oxidation of Trace Organic Contaminants by Hydrogen Peroxide Photolysis and Fenton's Reaction, *Industrial & Engineering Chemistry Research*, 49, 11331–11343.
- Stasinakis, A. S., G. Gatidou, et al. 2008. Occurrence and fate of endocrine disrupters in Greek sewage treatment plants. *Water Research* 42(6-7): 1796-1804.
- Vajda, A.M., Barber, L.B., et al. 2008. Reproductive disruption in fish downstream of an estrogenic wastewater effluent. *Environmental Science & Technology*. 42(9), pp 3407–3414.
- Wang, S., R. M. Holzem, et al. 2008. Effects of pharmaceutically active compounds on a mixed microbial community originating from a municipal wastewater treatment plant. *Environmental Science & Technology* 42(4): 1091-1095.

Extraction Methods for Engineered Nanoparticles From Aqueous Environmental Samples

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Principal Investigators:	Paul Westerhoff, Yu Yang

Publication

1. Yang, Y.*, Westerhoff, P., Hristovski, K. Cloud Point Extraction and Characterization of Nanomaterials from Water, in preparation

Extraction Methods for Engineered Nanoparticles from Aqueous Environmental Samples

A. Problem and Research Objectives

The development of nanotechnology has inevitably generated a large amount of engineered nanomaterials (ENMs) applied in industry and consumer products (Li and Chen, 2011; Meyer et al., 2009; Ripp and Henry Theodore, 2011). Nanomaterials incorporated with silver (Ag), titanium (Ti) and zinc (Zn) represent 50%, 10%, and 10% in commercial nanomaterials, respectively (Meyer et al., 2009). The application of ENMs in cosmetics and clothing products (e.g., fabric, sunscreens, and lotion) has increased the potential exposure to human beings and environment (Benn and Westerhoff, 2008; Popov et al., 2005; Reinhart et al., 2010; Yang et al., 2013). Nanomaterials in consumer products can be released to sewer system and surface water through washing and other processes (Benn and Westerhoff, 2008; Kiser et al., 2009). With increasing concerns of toxicity of ENMs, an effective method for detection or characterization of ENMs in natural water bodies or wastewater is in urgent need.

There is limited information about the morphologies of ENMs in natural water environment. The estimated concentrations of ENMs are low in surface water and the effluent of sludge treatment plant, which are in the range of 0.002 -1.75 $\mu\text{g/L}$ for nano TiO_2 , 0.001 – 0.3 $\mu\text{g/L}$ for nano ZnO , and 0.116 – 21 ng/L for nano Ag, respectively (Gottschalk et al., 2009). In order to quantify and characterize ENMs in water, an enrichment method is presumably required to concentrate the ENMs and preserve their nano size and shape. Current size separation techniques such as size exclusion chromatography (Al-Somali et al., 2004; Liu et al., 2009), hydrodynamic chromatography (Chmela et al., 2002) are effective in size detection but time consuming.

Multiple methods have been developed to facilitate the transfer of ENMs from liquid phase to organic phase, such as surfactant (e.g. Triton X – 114), ionic liquid, n-Alkanethiols (Garcia-Martinez and Crooks, 2004; Liu et al., 2009; Wilson et al., 2004). Among those methods, cloud point and ionic extraction methods are simple and noninvasive, both of which can be easily operated in a chemical lab (Liu et al., 2009; Wei et al., 2004). Solid phase extraction (SPE) has been applied for extraction and quantification of aqueous fullerenes in urine (Benn et al., 2011). Thus it is necessary to compare these methods and finally rule out a robust protocol for rapid analysis of ENMs in environmental solution.

The goal of this project was to evaluate the different extraction methods in extracting and concentrating nanomaterials from the water. Nano Ag and or nano Au were used to examine the extraction efficiency on each method. After comparison among cloud point extraction (CPE), ionic liquid extraction (ILE), and solid phase extraction (SPE), the method with the best extraction efficiency was used to extract potential ENMs from the natural water. After extraction, the concentrated ENMs were characterized by transmission electron microscopy coupled with an energy dispersive X-ray spectroscopy (TEM-EDX).

B. Methodology

Different types of ENMs and experiment methods were summarized in the below. Detailed experiment designs for each extraction method were addressed. All laboratory solutions were prepared from nanopure water (NANO pure Infinity Ultra-pure Water System). All glassware was acid washed and then cleaned with nanopure water. All chemicals were reagent grade and purchased from Sigma-Aldrich unless otherwise stated.

1). Sources and Characterization of Nanomaterials

ENMs with different sizes and capping agents were used in this study. Nano Ag and nano Au stabilized with citric acid or polyvinyl pyrrolidone (PVP) were synthesized with different sizes in a range of 25-100 nm (Yang et al., 2012). The hydrodynamic diameters of nano Ag and Au were determined by phase analysis light scattering (ZetaPALS, Brookhaven Instruments Corporation, New York). A food-grade titanium dioxide was obtained from a supplier in China with an averaged diameter of 124 nm, while 20% of them were below 100 nm in diameter by number. The other TiO₂ nanoparticle-Aeroxide P25 (Degussa) with an average particle size of 23 nm was obtained from EvonikDegussa Corporation (Weir et al., 2012). Colloidal nano SiO₂ particles used as chemical polishing agent were obtained from an industrial supplier, which was 36 nm in diameter.

2). Ionic Liquid Extraction on Nano Au Suspension

To explore the extraction efficiency of IL on nano Au stabilized with citrate, an aqueous solution containing gold nanoparticles (5 mg/L, diameter = 50 nm) was added to the [BMIM][PF₆] at the volume ratios of 3:1, 10:1, and 30:1, respectively (Wei et al., 2004). The mixture of each suspension was vortexed for 2 minutes and centrifuged at 3,000 rpm ($F = 978G$) for 5 minutes. The whole suspension did not show separation of nano Au from the water after 20 minutes. Thus the setting of whole suspension extended to 24 hours to get the phase separation between water and ionic liquid. The Au concentration in the supernatant was analyzed by UV-Vis (DR 5000, Hach, Colorado). The extract efficiency was calculated as following:

Extract efficiency = $(C_0 - C_1)/C_0$, where C_0 equaled to the initial concentration of nano Au suspension, and C_1 equaled to the final concentration of nano Au in the supernatant after extraction.

3). Solid Phase Extraction on Nano Ag Suspension

Silver nanoparticle stabilized with citric acid (diameter = 50 nm) was used for SPE experiment. SPE was conducted using 500 mg/6 mL Strata C18-E cartridges with 55- μ m particles and 70-Å pore size (Phenomenex, Torrance, CA). Detailed procedures followed the protocol developed in our lab (Benn et al., 2011). The only difference was the final elution solution, which was 10 mL methanol in this study. Since there was no detectable silver in final eluted solution and likely they were trapped by the column, SPE by Strata C18-E cartridges was not suitable for extraction of nano Ag particle unless further efforts could be made on column modification and process optimization.

4). Cloud Point Extraction on Nanomaterials

An aliquot of 9.5 mL of nanoparticle suspension was placed in a 15 mL of clean centrifuge tube. The pH was adjusted to around 3 to get the maximum extraction efficiency by 1% of nitric acid (Liu et al., 2009), and then 0.1 mL of sodium nitrate (3.5 M) was added to increase the ionic

strength. An aliquot of 0.4 mL of Triton X-114 (5%, W/V) was introduced to the mixture solution. The centrifuge tube with mixture was then water bathed for 30 minutes at 40 °C. After cooling down to the room temperature, centrifuge tubes were centrifuged at 3,000 rpm ($F = 978\text{ G}$) for 5 minutes. After setting for 30 minutes, the supernatant was pipette out and the enriched Triton X-114 phase (~0.4 mL, named cloud phase in this report) was obtained at the bottom of the tube. The enriched cloud point phase was acid digested and the concentrations of elements were analyzed by inductively coupled plasma mass spectrometry (ICP-MS). Extract efficiency equaled to M_1/M_T , where M_1 means the mass of ENM extracted in the separated cloud phase, and M_T means the total mass of ENM added to the initial suspension.

In order to explore the effect of size of nano Au on CPE, CPE tests were performed on three types of nano Au with hydrodynamic diameter of 3.2 nm, 50 nm, and 87 nm, respectively. The enriched cloud phase (0.4 mL) was resuspended to 10 mL by methanol, sonicated in a water bath for 10 minutes, and analyzed by UV-Vis.

For prospecting ENMs in environment water, CPE was performed on various types of waters including samples from Salt river, Verde river, influent and effluent from a wastewater treatment plants (WWTPs), Saguaro lake, and Tempe Canal. The same procedure was applied to extract ENMs from the water except 9.5 mL of water sample. The final enriched Triton X-114 phase with nanomaterials was characterized by TEM-EDX.

5). TEM-EDX Analysis on Nanomaterials Extracted in Cloud Phase

An aliquot of 20 μL of the cloud phase (Triton X-114 enriched) sample was placed on copper TEM grid. Before the grid was placed into the chamber for electron microscopy analysis, the TEM grid with sample was dried under a 100-W heat light to remove organic things on the TEM grid. The imaging was conducted on a TEM (STEM Phillips CM-200) coupled with EDX (Doudrick et al., 2012).

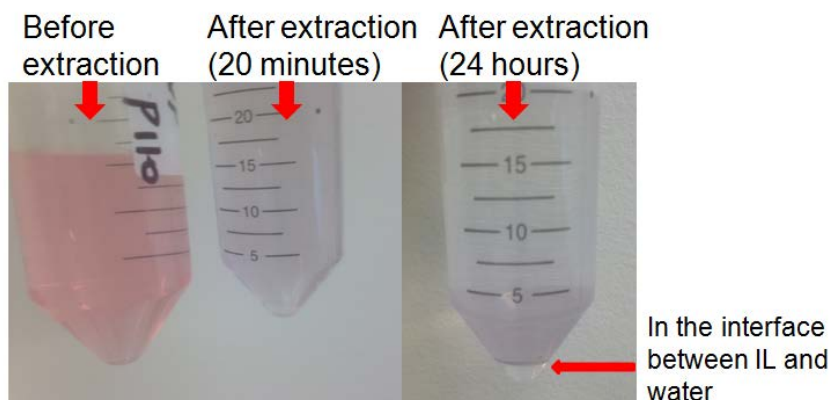
C. Principal Findings and Significance

1). Ionic Liquid Extraction on Nano Au Suspension

Ionic liquid [BMIM][PF6] showed the ability to remove the nano Au from the water phase. However, a long setting time (24 hour) was required to get the phase separation (Figure 1). After setting for 20 minutes, nano Au still suspended in the whole solution. After 24 hours, we could observe a clear phase separation of IL and water (Figure 1). Based upon monitoring the Au concentration in the supernatant, the [BMIM][PF6] demonstrated the ability of transferring nano Au from the water phase (Table 1). However, the removed Au accumulated in the interface between water and IL by capillary force (Frost and Dai, 2012). Therefore, ILE was not further applied to extract ENMs in other environmental water samples.

Table 1. The Percentage Removed of Au Concentration in the Water Phase

Volume of [BMIM][PF6] (mL)	AuNP-solution (mL)	Percentage
0.3	3	97%
0.3	15	98%
0.3	30	96%

**Figure 1. Nano Au Suspension before and after the ILE.**

2). Cloud Point Extraction on Nanomaterials in Clean Water

Figure 2 shows the varied extraction ability of Triton X-114 on different types of ENMs. The extraction efficiencies for food-grade TiO_2 and P25 TiO_2 were 83% and 85%, respectively. Almost 100% of CMP- SiO_2 was extracted into about 0.40 mL of cloud phase (Triton X-114). About 79% of nano Au stabilized by tannic acid was extracted out. However, CPE only extracted about 21% of nano Ag stabilized by PVP. Our results were consistent with previous findings, which demonstrated a high extraction efficiency on a variety of ENMs including nano Au, nano Ag, quantum dots (CdSe/ZnS), C60, SWCNT (Liu et al., 2009). Though the exact reason was unknown about why nano Ag-PVP showed relative lower extraction efficiency in CPE, likely the capping agent of PVP on nano Ag may increase the stability and thus being more reluctant to form micelle in cloud point phase.

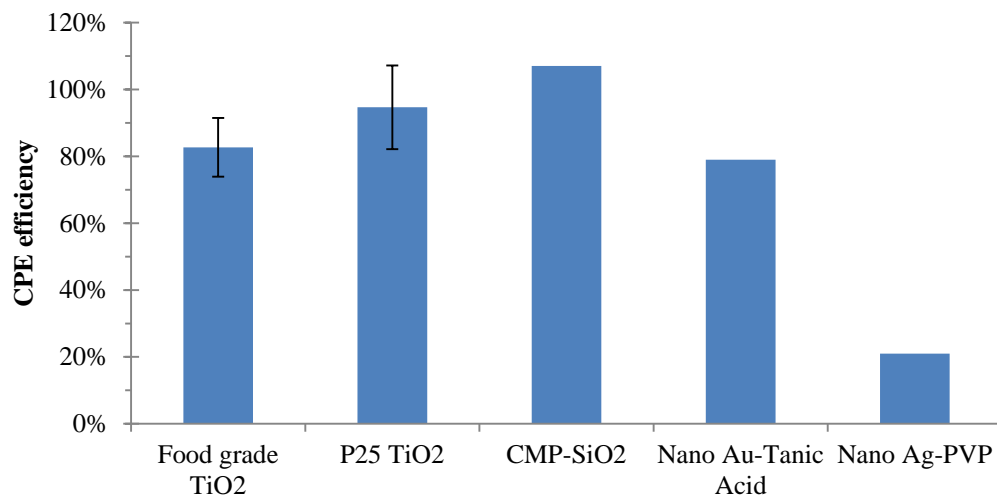


Figure 2. Extraction efficiency of CPE on a variety of nanomaterials in water

Another batch study was performed to explore the impact of NM size on CPE efficiency. Nano Au stabilized by citrate was used for CPE test. Nano Au with diameter of 3.2 nm, 50 nm, and 87 nm showed extraction efficiencies of $95.8 \pm 5.9\%$, $100 \pm 2.4\%$, and $96.7 \pm 2.4\%$, respectively (Figure 3). Thus there was no impact of particle size on CPE efficiency when extracting nano Au stabilized by citrate, and CPE is suitable for a wide range size of particles.

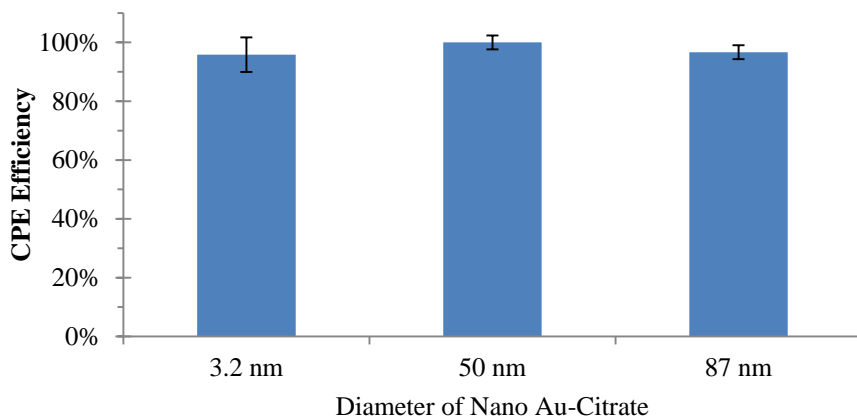


Figure 3. Extraction efficiency of CPE on nano Au stabilized by citrate.

3). Cloud Point Extraction and Characterization of Nanomaterials in Environmental Water

CPE by Triton X-114 can not only enrich the ENMs but also separate metallic particles from ions (Chao et al., 2011; Liu et al., 2009; Yu et al., 2013). Therefore CPE by Triton X-114 can eliminate the interference brought by metal ions. Figure 4 presents the representative TEM images of ENMs extracted by CPE from environmental water samples. Nano TiO₂ was identified in Salt River with a primary diameter of 60 nm, and a large aggregate of nano TiO₂ was identified. A nanoparticle containing elements of iron, carbon, and oxygen showed up in Verde

River sample, with a maximum diameter was 93 nm. In the tap water, SiO_2 and TiO_2 particles were found with diameters around 98 and 122 nm, respectively. We have identified calcium carbonate like nanoparticle ($\text{Ca} + \text{C} + \text{O}$) in the influent of WWTP, while nano SiO_2 particles appeared in the effluent of WWTP with diameters of 78-80 nm. There was no silver or gold containing particle being identified over 12 samples for CPE and TEM analysis. All the information from Figure 4 was summarized in Table 2.

Results from Figure 4 also indicate that the most common ENMs in water could be nano TiO_2 and SiO_2 , since both of them were periodically found in water. Though the sources of nano TiO_2 were not identified yet, likely they could be released from the sunscreen or other consumer products (Weir et al., 2012). Washing of textiles incorporated with TiO_2 releases titanium into the water environment (Windler et al., 2012). Nano SiO_2 particle could be anthropogenic sources like CMP polishing process (Weir et al., 2012) or natural sources. Further research will be conducted to track the source of ENM in water.

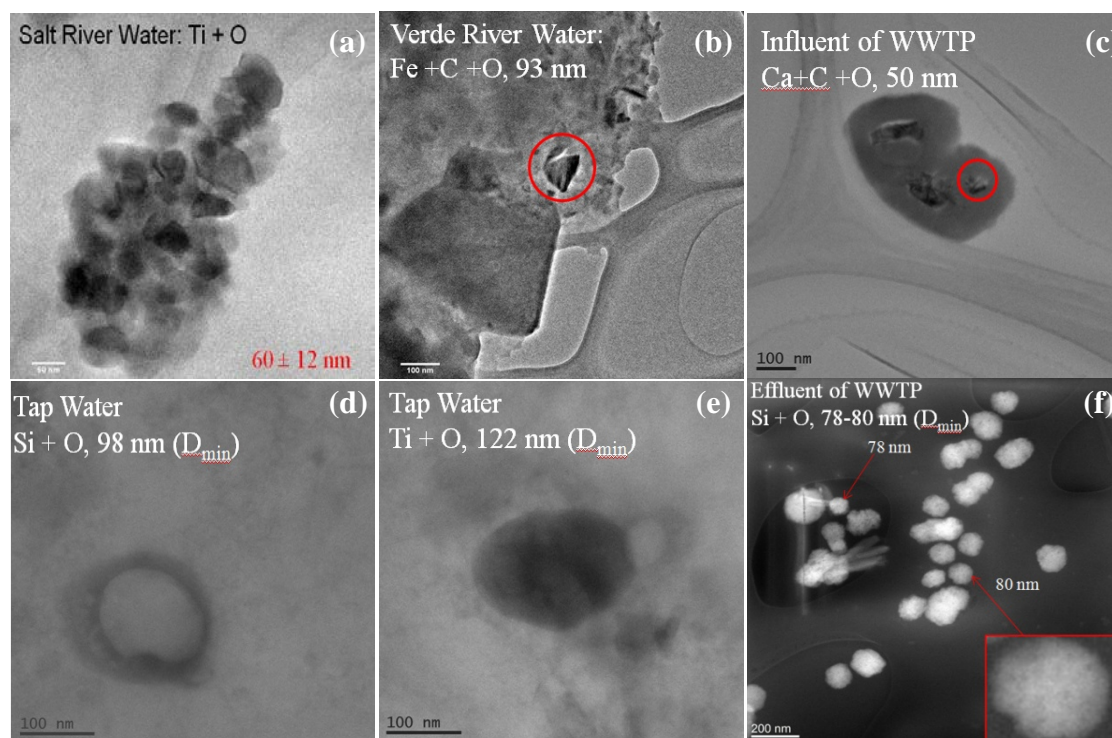


Figure 4. Characterization on extracted ENMs from environmental water by transmission electron microscopy (TEM) and energy dispersive X-ray spectroscopy (EDX).

Table 2. Summary of all the Particles Extracted from Water by TEM/EDX

Major elements detected by TEM/EDX	Minimum Diameter (nm)	Sources of Water Samples
Ti + O (Titanium dioxide)	4, 60 ± 12, 108	Salt, Verde River, Canal, and tap water
Si + O (Silica)	50 - 220	Effluent of WWTP
C + Ca + O (Calcium carbonate)	61 - 109	River and tap water
Fe + C + O	93	River water
C+ O + Si + Ca (Amorphous)	200 - 377	River, tape water, and Effluent of WWTP

* No silver/gold particles were identified.

4). Summary

We have examined the application of SPE, ILE, and CPE on a variety of ENMs in water. SPE works well for fullerene extraction demonstrated in our previous research, and it could not be applied to extract metallic nanoparticles in water. ILE by [BMIM][PF6] could be applied to separate ENMs from water, however, all the nanomaterials stay in the interface between the water and ionic liquid. CPE by Triton X-114 demonstrated the ability to enrich a list of ENMs including nano Au, TiO₂, and SiO₂ with varied size and capping agent. Therefore, CPE by Triton X-114 has been applied to extract potential ENMs in environmental water samples and further characterized by TEM-EDX. The most abundant nanoparticles identified so far were Si and Ti containing particles with diameter in the range 4-99 nm. Other nanoparticles ranged from 30-65 nm contained a list of major elements, including calcium, magnesium, aluminum, iron, oxygen, sulfur, carbon, and chloride. Generally, CPE coupled with TEM-EDX can be applied as an effective tool to enrich and characterize ENMs in environmental water. Further research is needed to quantify the ENM concentration in the environmental water.

References

- Al-Somali, A.M., Krueger, K.M., Falkner, J.C. and Colvin, V.L. (2004) Recycling Size Exclusion Chromatography for the Analysis and Separation of Nanocrystalline Gold. *Analytical Chemistry* 76(19), 5903-5910.
- Benn, T., Pycke, B., Herckes, P., Westerhoff, P. and Halden, R. (2011) Evaluation of extraction methods for quantification of aqueous fullerenes in urine. *Analytical and Bioanalytical Chemistry* 399(4), 1631-1639.
- Benn, T.M. and Westerhoff, P. (2008) Nanoparticle Silver Released into Water from Commercially Available Sock Fabrics. *Environmental Science & Technology* 42(11), 4133-4139.

- Chmela, E., Tijssen, R., Blom, M.T., Gardeniers, H.J.G.E. and van den Berg, A. (2002) A Chip System for Size Separation of Macromolecules and Particles by Hydrodynamic Chromatography. *Analytical Chemistry* 74(14), 3470-3475.
- Choi, O., Deng, K.K., Kim, N.J., Ross Jr, L., Surampalli, R.Y. and Hu, Z. (2008) The inhibitory effects of silver nanoparticles, silver ions, and silver chloride colloids on microbial growth. *Water Research* 42(12), 3066-3074.
- Doudrick, K., Monzon, O., Mangonon, A., Hristovski, K. and Westerhoff, P. (2012) Nitrate Reduction in Water Using Commercial Titanium Dioxide Photocatalysts (P25, P90, and Hombikat UV100). *Journal of Environmental Engineering-Asce* 138(8), 852-861.
- Franklin, N.M., Rogers, N.J., Apte, S.C., Batley, G.E., Gadd, G.E. and Casey, P.S. (2007) Comparative toxicity of nanoparticulate ZnO, bulk ZnO, and ZnCl₂ to a freshwater microalga (*Pseudokirchneriella subcapitata*): The importance of particle solubility. *Environmental science & technology* 41(24), 8484-8490.
- Garcia-Martinez, J.C. and Crooks, R.M. (2004) Extraction of Au Nanoparticles Having Narrow Size Distributions from within Dendrimer Templates. *Journal of the American Chemical Society* 126(49), 16170-16178.
- Gottschalk, F., Sonderer, T., Scholz, R.W. and Nowack, B. (2009) Modeled Environmental Concentrations of Engineered Nanomaterials (TiO₂, ZnO, Ag, CNT, Fullerenes) for Different Regions. *Environmental Science & Technology* 43(24), 9216-9222.
- Kiser, M.A., Westerhoff, P., Benn, T., Wang, Y., Pérez-Rivera, J. and Hristovski, K. (2009) Titanium nanomaterial removal and release from wastewater treatment plants. *Environmental Science and Technology* 43(17), 6757-6763.
- Li, Y.-F. and Chen, C. (2011) Fate and Toxicity of Metallic and Metal-Containing Nanoparticles for Biomedical Applications. *Small* 7(21), 2965-2980.
- Liu, J.-f., Liu, R., Yin, Y.-g. and Jiang, G.-b. (2009) Triton X-114 based cloud point extraction: a thermoreversible approach for separation/concentration and dispersion of nanomaterials in the aqueous phase. *Chemical Communications* (12), 1514-1516.
- Meyer, D.E., Curran, M.A. and Gonzalez, M.A. (2009) An Examination of Existing Data for the Industrial Manufacture and Use of Nanocomponents and Their Role in the Life Cycle Impact of Nanoproducts. *Environmental Science & Technology* 43(5), 1256-1263.
- Popov, A.P., Priezzhev, A.V., Lademann, J. and Myllylä, R. (2005) TiO₂ nanoparticles as an effective UV-B radiation skin-protective compound in sunscreens. *Journal of Physics D: Applied Physics* 38(15), 2564.
- Reinhart, D.R., Berge, N.D., Santra, S. and Bolyard, S.C. (2010) Emerging contaminants: Nanomaterial fate in landfills. *Waste Management* 30(11), 2020-2021.
- Ripp, S. and Henry Theodore, B. (eds) (2011) *Biotechnology and Nanotechnology Risk Assessment: Minding and Managing the Potential Threats around Us*, American Chemical Society.
- Thomas, C., Saleh, N., Tilton, R.D., Lowry, G.V. and Veronesi, B. (2006) Titanium dioxide (P25) produces reactive oxygen species in immortalized brain microglia (BV2): implications for nanoparticle neurotoxicity. *Environmental science & technology* 40(14), 4346-4352.
- Wei, G.-T., Yang, Z., Lee, C.-Y., Yang, H.-Y. and Wang, C.R.C. (2004) Aqueous - Organic Phase Transfer of Gold Nanoparticles and Gold Nanorods Using an Ionic Liquid. *Journal of the American Chemical Society* 126(16), 5036-5037.

- Weir, A., Westerhoff, P., Fabricius, L., Hristovski, K. and von Goetz, N. (2012) Titanium Dioxide Nanoparticles in Food and Personal Care Products. *Environmental Science & Technology* 46(4), 2242-2250.
- Wilson, O.M., Scott, R.W.J., Garcia-Martinez, J.C. and Crooks, R.M. (2004) Synthesis, Characterization, and Structure-Selective Extraction Extraction of 1-3-nm Diameter AuAg Dendrimer-Encapsulated Bimetallic Nanoparticles. *Journal of the American Chemical Society* 127(3), 1015-1024.
- Yang, Y., Zhang, C. and Hu, Z. (2013) Impact of metallic and metal oxide nanoparticles on wastewater treatment and anaerobic digestion. *Environmental Science: Processes & Impacts*.

Award--IEIWaRM Streamflow Forecasts Africa

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Principal Investigators:	Sharon B. Megdal, Juan Valdes

Publications

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2. Merino, Manuel, Aleix Serrat-Capdevila, Juan B Valdes, Matej Durcik (2014) Evaluation of the Performance of three satellite precipitation products over Africa (In preparation, to be submitted)
3. Serrat-Capdevila, Aleix, Manuel Merino, Juan B Valdes, Matej Durcik, Khalidou Ba (2014) Hydrologic simulations of three poorly gauged watersheds of the Senegal River using a lumped and a distributed model with different rainfall inputs (In preparation, to be submitted soon)

Report Contents for

Integrating African Hydrologic Initiatives

Using satellite products to support water monitoring and forecasting in Africa

Aleix Serrat-Capdevila, Juan Valdes, Khalidou Ba, Matej Durcik, Manuel Merino

a. Problem and Research Objectives

This project aims at integrating existing water resources monitoring and forecasting efforts in West Africa in a meaningful and holistic manner for the benefits of decision-makers. It is a perception that water-related decision making in Africa does not make use of state of the art capabilities due to many challenges, including the difficulties of using uncertain information and predictions in decision-making activities. The proposed work combines original applied research with coordination of activities in parallel efforts as described in two main axes:

(1) Streamflow Forecast System: Consolidating and validating recently developed multi-model remote-sensing applications and capabilities to monitor water resources availability and provide 7 to 12 day streamflow forecasts in key pilot watersheds in the International Senegal Basin. Two hydrologic models of three watersheds in the Senegal Basin are currently functional and a third one is currently under development. Automated forecasts will be developed using the previous three models and a system to retrieve different satellite precipitation estimates in real time. The system will also incorporate the use of near-term weather forecasts as inputs for hydrologic modeling, with a multi-model approach. The developed applications will directly support a range of drought prediction, assessment, adaptation and monitoring activities in support of food, energy and livelihood security. Streamflow forecasting will inform water availability for both energy production in the Manantali Dam and competing downstream uses such as irrigated agriculture, flood recession agriculture, urban supply and others. The current project emphasizes the near real-time aspect of precipitation data and hydrologic modeling. Recent research has shown that even in poorly gauged regions, hydrologic simulations using spatially explicit and data intensive satellite precipitation estimates are generally inferior or equal in performance to simulations using a handful of rain gauges (Stisen and Sandholt 2010; Nishat and Rahman, 2009; Habib et al. 2009; Harris et al. 2007). This can be attributed to the following reasons: (a) satellite precipitation products have had a low level of accuracy (due to rain rate measurement errors, or errors in interpolation between satellite overpasses/measurements); (b) studies often use global satellite products with very simple or no bias correction; (c) hydrologic models are sometimes not re-calibrated with satellite precipitation estimates before simulation (Serrat-Capdevila et al., 2011d).

On the other hand, satellite products are the only near real-time precipitation estimates available globally. Past studies use existing records of a-posteriori available rain-gauge data and do not consider the constraints of data availability at the near real-time, when it would be most useful to water management operations. In large basins in developing regions most of the rain-gauge data

becomes available weeks or months after it has been recorded, due to the lack of automatic data retrieval systems. Thus, in such settings, only satellite precipitation products are available to drive near real-time hydrologic streamflow forecasts. Yet there are currently no publicly available operational applications of this type with resolutions useful to water managers in these countries.

The project will benefit from a strong linkage with the end-user communities through our partnership with the International Senegal basin Authority (OMVS, Organisation pour la Mise en Valeur du Fleuve Senegal, 4 member states). The outcomes from this initiative will directly inform and be exchanged with similar parallel efforts with AGRHYMET Regional Center in the Sahel (9 member states in Sub-Saharan Africa), and the Southern Africa Development Community Climate Services Center (SADC – CSC), formerly the Drought Monitoring Center (15 member states in Southern Africa).

(2) Integration of Parallel Efforts: A number of efforts by different institutions are currently being developed in Africa with a focus on water resources monitoring, such as the African Drought Monitor (ADM) at Princeton University (Eric Wood and Justin Sheffield research group). While the ADM is currently an independent effort, we are of the opinion that there could be many levels of integration whose benefits would be greater than the sum of the parts. Working with the Princeton ADM team, we intend to compare our multi-model simulations with the simulations of the VIC model from the ADM for our specific case-study basins. These integration efforts will be beneficial for hydrologic model evaluations, VIC model calibration aspects, satellite product performance evaluations, and forecast uncertainty quantification. Findings will be able to inform parallel efforts across the African Continent.

In addition, other capacity building activities such as workshops and lectures in meetings have also been carried out in a number of international settings, relating to the use hydrologic modeling and satellite precipitation monitoring for water management applications.

Forecast products – such as near-real time streamflow forecasts, benefitting from end-user feedback – will be made widely available not only through the end-users desired local and regional means, but also globally through the web.

b. Methodology

The methodology of the activities has been divided for clarity in three sections describing (1) consolidation and validation of a streamflow forecasting system, and (2) integration and comparison with parallel African Drought Monitor efforts.

Finalizing a streamflow forecasting system in the Senegal Basin:

One of the main activities has been the completion, validation and automatization of a near-term streamflow forecasting system in key pilot basins of the Senegal Basin. This was accomplished using (a) three near real-time satellite estimates of precipitation: PERSIANN, CMORPH, TMPA; (b) regional databases of ground observations with which to correct biases and calibrate

applications; (c) a near term numerical model precipitation forecast (from NOAA); and (d) the use of hydrologic models to simulate the hydrologic cycle and produce streamflow forecasts using a multi-model approach.

(a) Satellite Observations:

Precipitation: Different global near real-time precipitation products will be evaluated and used during this project: CMORPH (Climate Prediction Center Morphing Technique), TMPA (TRMM Multisatellite Precipitation Analysis) and PERSIANN (Precipitation Estimation from Remote Sensing Information using Artificial Neural Network). These three satellite precipitation products have almost global coverage (up to 60 degrees latitude N and S, excluding polar regions) and their estimates appear online only a few hours after the measurements have been made. Such near real-time data as well as the archives of past measurement history are publicly available in the internet and easily accessible from anywhere in the world. They provide a spatially explicit continuous global observation database of precipitation. Figure 1 shows the evolution of precipitation over the Senegal Basin as the Inter-Tropical Convergence Zone (ITCZ) migrates North and then South, as captured by PERSIANN precipitation estimates.

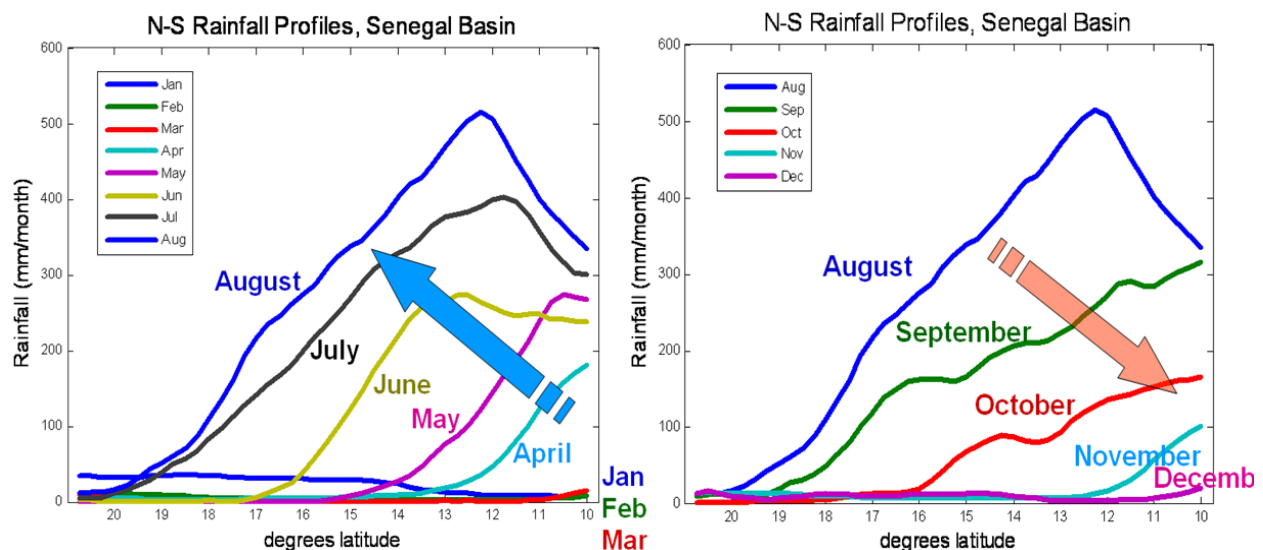


Figure 1: The migration North (left) and South (right) of the Inter-Tropical Convergence Zone (ITCZ) represented by the N-S monthly rainfall profiles as captured by PERSIANN over the Senegal River Basin in West Africa during year 2004 (Figure from A. Serrat-Capdevila).

Bias correction and regional validation of near real-time satellite products has been done using available ground rain-gage measurements. Two types of bias corrections have been used: an annual correction to adjust the annual means and a probability density function matching technique to adjust quantile values of satellite precipitation products with those of the observation distributions.

(b) Ground Observations:

Precipitation, ET and Streamflow: The OMVS has the largest observational database of precipitation, streamflows and other variables, in the international Senegal River Basin, spanning

four countries. AGRHYMET has without doubt the largest rainfall database in the Sahel Region (see Fig. 2) and hands-on knowledge about local meteorology and hydrometeorology measurements. These available ground rainfall and streamflow databases will be essential to compare and evaluate – and in some cases calibrate – satellite precipitation products as well as to calibrate hydrologic simulations and test their accuracy and reliability. Figure 2 provides an example of a characterization of a streamflow climatology based on available records (almost 100 years long) for the Bafing tributary in the town of Makana.

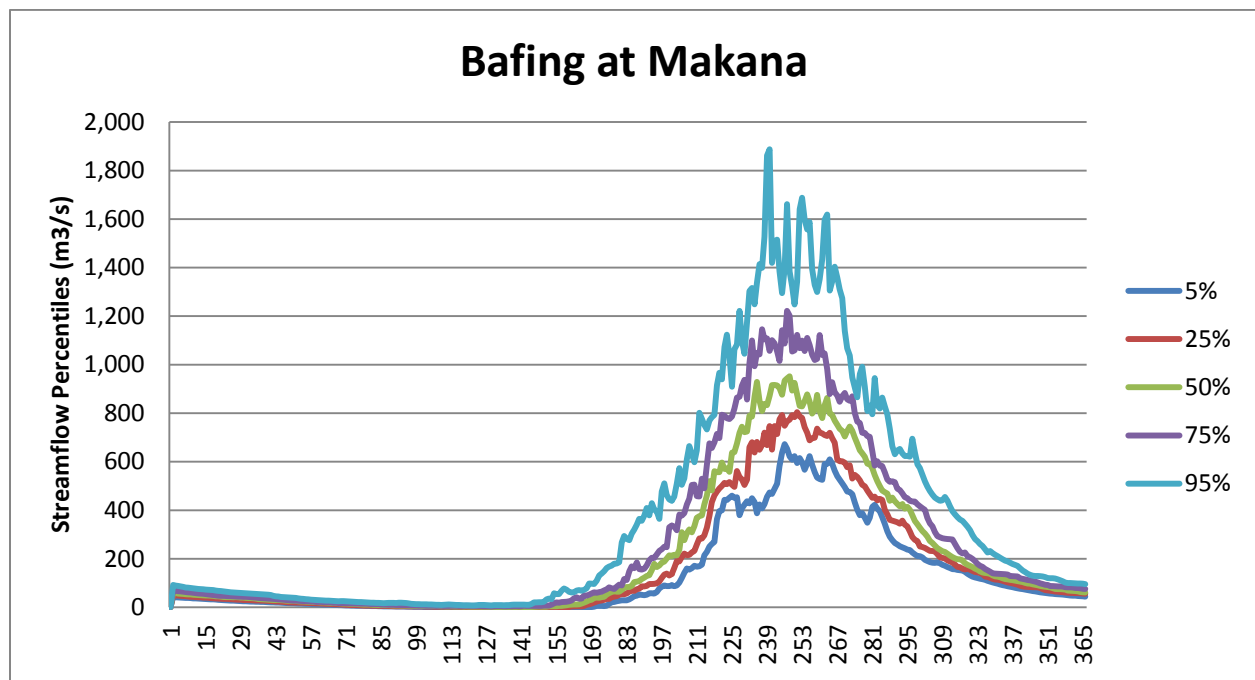


Figure 2: Characterization of the climatology of streamflows with percentiles for the Bafing at the town of Makana, in the Upper Basin. Streamflow records can span one hundred years and belong to the member countries and the OMVS.

(c) Numerical weather model data:

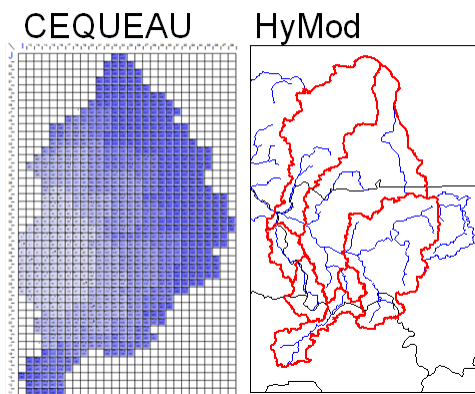
Precipitation forecasts from numerical weather prediction models have been used to extend precipitation estimates into the future and provide additional lead time in the streamflow forecasts after the most recent satellite rainfall measurements. In other words, if we have yesterday's satellite rainfall measurements and run a hydrologic simulation that will issue predicted streamflows for the next 7 to 12 days, these streamflows can be affected by future precipitation occurring in the basin within these 7 to 12 days. If decisions are being taken today, based on predicted streamflows for the next 7 to 12 days, the expectation of having additional rainfall (or lack of it) should be accounted for in the streamflow predictions. Thus, hydrologic simulations in this work are driven by (A) measured remote sensing of precipitation up to the present and (B) forecasted precipitation over the next 7 to 12 days, issued from a numerical weather model (NOAA-CPC).

(d) Hydrologic modeling:

A multi-model simulation approach will be adopted in this proposal. Personal communications from the region have stated the fact that institutions approach them with individual models to test, but to date none has been found to perform uniformly well in the region. A multi-model approach allows us to understand what works best in the region and why. The other important reason for a multi-model approach is to allow flexibility in the participation of end-users and stakeholders, maximizing the probabilities of appropriation and use by end-users. Such a multi-model approach (including both simple and complex models) is an innovative aspect of this proposal. In this work we have used two models:

(1) A simple lumped or semi-distributed model named *HyMod*, easily calibrated and with only 6 parameters. The calibration of the model has been done with the Shuffled Complex Evolution (SCE-UA) algorithm (Duan et al. 1992).

(2) A distributed model using the modeling platform CEQUEAU. Among the many available models of watershed hydrology, the most popular ones have been described in important studies like WMO (1986), WMO (1992), Shing and Frevert (2002). The CEQUEAU hydrological model (Morin et al., 1998, Morin and Paquet, 2007, Ba et al, 2009a, Ba et al, 2009b, Díaz Mercado and Ba et al., 2010) is a distributed model that has been included in these studies. Recently, a new version of the CEQUEAU model has been developed and tested in Mexico (Díaz-Mercado, Ba et al., 2010).



The distributed model of the Senegal Basin was calibrated with historical rain-gauge data against historical streamflows, as well as re-calibrated using bias-adjusted satellite precipitation data. The parameters of the CEQUEAU models can be calibrated by trial and error, by numerical optimizations or by the combination of these two methods.

Figure 3: Distributed and Semi-lumped model setups for the Senegal Basin.

Co-development and Appropriation by End-Users:

This project has benefited from meetings and capacity building activities in parallel projects in which we have attempted to get feedback from regional stakeholders and end-users regarding their management and information needs and the design and functioning of monitoring and forecasting tools. During these workshops the preliminary applications and capabilities have been presented as something that can be adapted and jointly modified to best serve their needs as decision-makers and end-users. In one of the workshops a participatory exercise was designed to engage and stimulate the audience, eliciting information and new solutions. These participatory exercises were geared to retrieving detailed information regarding decision-making processes and what sets of data and information come into play in each decision domain.

(2) Integration Efforts and Comparison with the African Drought Monitor & others

A number of efforts by different institutions are currently being developed in Africa with a focus on water resources monitoring, such as the African Drought Monitor (ADM) at Princeton University (Eric Wood and Justin Sheffield research group). While the ADM is currently an independent effort, we have identified many levels of collaboration and integration whose benefits would be greater than the sum of the parts. Working with the Princeton ADM team, we have done some preliminary comparisons of our multi-model simulations with the simulations of the VIC model from the ADM for our specific case-study basins. These integration efforts and ongoing dialogue are beneficial for hydrologic model evaluations, VIC model calibration aspects, satellite product performance evaluations, and forecast uncertainty quantification. Findings and discussion are informing each other's and parallel efforts across the African Continent.

The project has created and benefitted from strong synergies with research institutes and projects spanning the African Continent, including West Africa and the Sahel, Eastern and Southern Africa. The investigators in this project are either involved or in communication with the following initiatives and efforts and a strong coordinating effort will be made among the following initiatives:

- NASA SERVIR Africa awarded a 4 year project to the University of Arizona to develop streamflow forecasts and water monitoring tools in three pilot basins in East and Southern Africa. The project will take a multi-product and a multi-model approach to hydrologic simulations and intends to interact significantly with regional decision-makers to produce adapted and useful water resources monitoring and forecasting tools. The obtention of the SERVIR award was greatly enabled by the current project.
- The Surface Hydrology Group at Princeton University operates the experimental African drought monitor. It provides Africa-wide estimates of precipitation (using TMPA), min and max air temperature, wind speed, evaporation, runoff, base-flow and soil moisture by running the VIC model at 0.25 degree resolution. They are getting this impressive application tested regionally and calibrated.
- NASA SERVIR and USAID have supported the development of some distributed models such as CREST (SERVIR) and the GeoSFM model by FEWS-Net (USAID-NOAA) for applications over Africa. FEWS-Net has been working in applications in Africa for a significant amount of time, bridging technical and human dimensions, and they will be a knowledgeable partner.
- The G-WADI program of UNESCO has been collaborating with the PERSIANN product and SAHRA in the development of the HyDis visualization tool, which shows the latest precipitation over the globe in near-real time.
- Other precipitation products, such as CMORPH, TMPA and the HydroEstimator do not have user friendly displays or visualization tools, but their estimates are available in near-

real time in the internet and they can be freely used for comparative studies and other purposes.

- Regional Hydrometeorological and Climate Institutes such as AGRHYMET and the Climate Services Center of the Southern Africa Development Community, as well as Management authorities such as the OMVS (Senegal Basin) have different levels of technical capacity but they have essential ground data repositories and they can provide the links with regional and local stakeholders and decision-makers. Their continued involvement has been highly beneficial.

c. Principal Findings and Significance

The findings in this report are structured in the form of hydrologic simulations performance tables, as well as model simulation plots with envelope of uncertainty and observations for visual comparison, and the display of an automated experimental forecasting system reporting online.

The performance of the hydrologic simulations in using rain gauges, three satellite products such as CMORPH, PERSIANN and TMPA (Real Time product 3B42RT) in their “Raw” form and after two types of bias corrections “BC1” and “BC2” are displayed in Table 1. The values of the table correspond to the Nash Sutcliffe Efficiency values from comparing simulated streamflows to observations, with a value of “1” signifying perfection, a value of “0” meaning that the forecast is as good as using the mean as a predictor and negative values reflecting performance worse than the mean. BC1 corresponds to a simple bias correction adjusting the annual means of satellite products to those of ground rainfall observations. BC2 refers to the bias correction method matching the probability distribution functions or quantile mapping approach. This was done for three basins, which range from 20,000Km², mountainous, more humid, vegetated and more linear shaped (Bafing until Makana, and Faleme until Gourbassi), to 80,000Km², more arid, flatter, rounded and with different sub-tributaries (Bakoye until Oualia).

Three available rain gauges have been used for this study, the first and second rain-gauges were averaged for use in the Bafing, one was used in the Faleme and the third-one was used for the Bakoye, although it was located outside and south of its sub-basin. It can be seen that the rain-gauges, although limited in number, are relatively good representing rainfall in the Bafing and Faleme sub-basins. However, that is not the case for the Bakoye. Generally performance (NSE values) of simulations using satellite precipitation products increase with the use of bias correction and hydrological simulations perform best in the smaller, more humid and linear shaped basins. Performance in the Bakoye is generally worst due to its flatter topography and the lumping of likely smaller-than-basin precipitation cells over the area of the sub-basin. This is the sub-basin where a distributed model would make most difference. It can also be observed that there is not a lot of difference between a simple bias correction such as the mean adjustment and a more sophisticated bias correction such as pdf matching. It is to note that TMPA estimates have a similar annual mean as the rain-gauge observations, hence the lack of BC1.

Table 1: Nash Sutcliffe Efficiency values for HyMod model hydrologic simulations in three Senegal Basin watersheds (horizontally) for the calibration and validation periods, and using the raw estimates and two types of bias corrections (adjusting the mean and matching the probability distribution functions) for three satellite precipitation products.

NSE Streamfl.	Rain Gauges	CMORPH			PERSIANN			TMPA (RT)		
		Raw	BC 1	BC 2	Raw	BC 1	BC 2	Raw	BC 1	BC 2
Bafing at Makana										
Calib.	0.85	0.67	0.81	0.84	0.54	0.84	0.83	0.81	-	0.83
Valid.	0.85	0.71	0.61	0.67	0.57	0.41	0.54	0.85	-	0.87
Faleme at Gourb.										
Calib.	0.80	0.04	0.67	0.63	-0.37	0.73	0.72	0.58	-	0.66
Valid.	0.80	0.54	0.64	0.71	-0.47	0.67	0.63	0.63	-	0.79
Bakoye at Oualia										
Calib.	-0.06	-5.53	0.78	0.24	-11.78	0.80	-0.06	0.51	-	0.59
Valid.	0.004	-0.62	0.51	0.11	-3.04	0.48	0.21	0.39	-	0.39

Table 2: Nash Sutcliffe Efficiency values for CEQUEAU hydrologic simulations in the entire Senegal Basin and in one of its watersheds (Bafing) for two satellite products and up to two types of bias corrections. Less simulations were done with this model because re-calibration was computationally difficult and time consuming. The CEQUEAU simulations were developed by Dr. Khalidou Ba during his sabbatical year in Tucson with Drs. Serrat-Capdevila and Valdes.

CEQUEAU NSE Streamfl.		Rain Gauges	CMORPH			PERSIANN		
			Raw	BC 1	BC 2	Raw	BC 1	BC 2
Bafing at Makana			(21,000 km ²)					
Calib.		0.75 1970-90	-	0.11	0.75		0.69	
Valid.		0.73 1991-2004	-	0.86	0.78		0.57	
Entire Senegal Basin at Bakel			(~300,000 km ²)					
PRE-DAM	Calib 1970-80	0.91		-			-	
	Valid 1981-84	0.85		-			-	
POST-DAM	Calib 1988-99	0.80	-	0.68 2003-05		-	0.84 2003-05	
	Valid 2000-04	0.75	-	0.70 2006-08		-	0.72 2006-08	

Table 2 shows that results from the CEQUEAU model present similar ranges of NSE, and also reflects the fact that a long effort of calibration of the entire basin (including the Bafing sub-basin) using a higher number of rain-gauges can be matched by satellite products with bias correction. However, while HyMod could be automatically and easily calibrated after coupling SCE optimization algorithm, the calibration of the CEQUEAU model was more laborious.

In addition to the previous simulations and analysis, an automated experimental forecast had been developed and setup using HyMod and CMORPH with a mean adjustment bias correction for year 2012, shown in Figure 4.

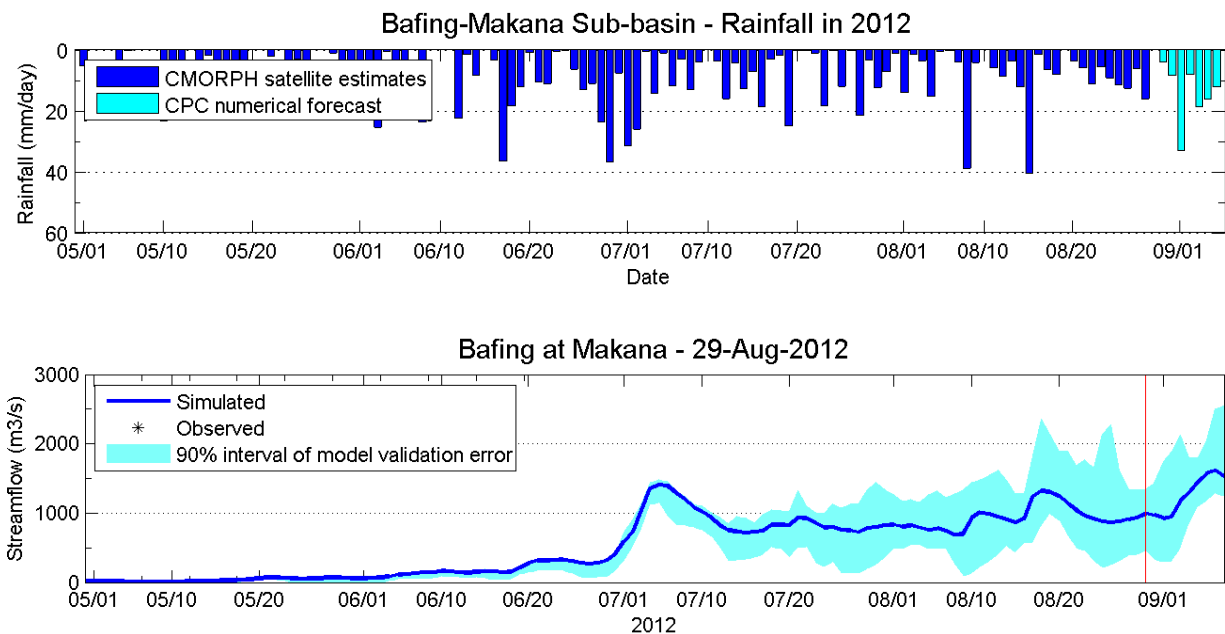


Figure 4: Lumped CMORPH precipitation time series (in blue) and CPC precipitation forecast from the Global Forecasting System, for the Bafing watershed until Makana (above). HyMod simulation and 10 day forecast (red line is the present) with an envelope of uncertainty showing 90% of the maximum errors incurred during the historical simulation period for that specific day of the year. This specific representation of model error can help water managers understand where the satellite precipitation products have missed an event as well as overestimated streamflows.

During year 2012 and part of 2013, this forecast system ran every day, downloading the latest satellite data corresponding to the previous day and the latest CPC precipitation forecast, and ran the HyMod model automatically providing an updated 10 day forecast every day. This was done for three basins and the results were displayed in a website at the following address: <http://newims.hwr.arizona.edu/SWAAT/SenegalRiver/>. Figures 5 and 6 show screen captures of the site with displays of the forecasts for December 2nd 2012.

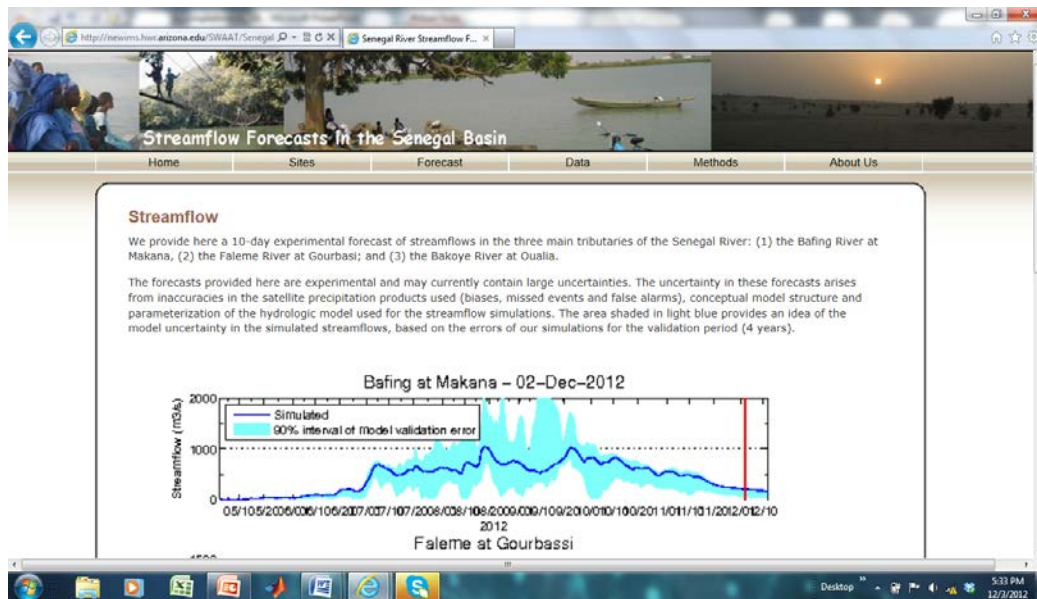


Figure 5: Screenshot of the Senegal Streamflow Forecasts website (I)

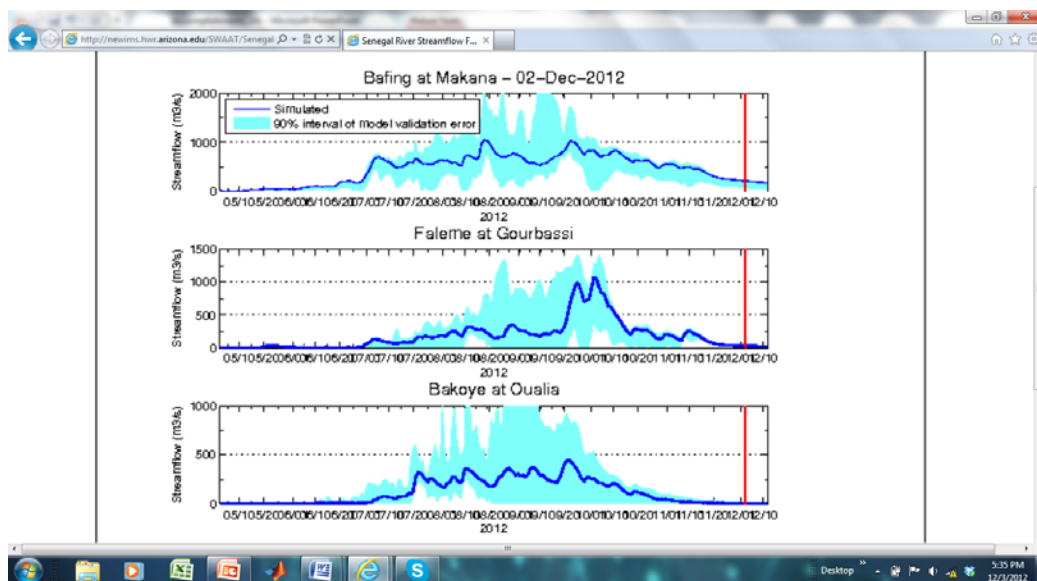


Figure 6: Screenshot of the Senegal Streamflow Forecasts website.

The Chief Hydrologist of the Organisation pour la Mise en Valeur du Fleuve Senegal was kept informed of the project progress, and the website address and the forecasts were shared with him, with the warning that such forecasts were experimental, its reliability had not been tested, and contained significant amounts of uncertainty. Sometime in mid-2013, this official sent us the streamflow observations for the three basins for year 2012, which are plotted in Figure 7. The plots in Figure 7 correspond to Bafing (top), Faleme (middle) and Bakoye (bottom). In the three plots observations fall mostly within the simulations uncertainty ranges. In the Bafing, although the system captures the occurrence of the big flood event, it completely underestimates its

magnitude. In the Faleme, showing the best results, all observations are contained in the uncertainty range and the two peaks of the yearly flood are captured, with relatively small errors in its magnitude and exact timing. However in the Bakoye, the forecast is the worst and even though the peaks are detected, their magnitude is severely underestimated. This is due to the fact that the storms creating the streamflow peaks are likely to have occurred in the south of the watershed not too far from the outlet (where it rains more due to the South-North gradient of precipitation in the Sahel), but in the HyMod model, the rain rate is averaged over the entire watershed, thus severely dampening the peaks.

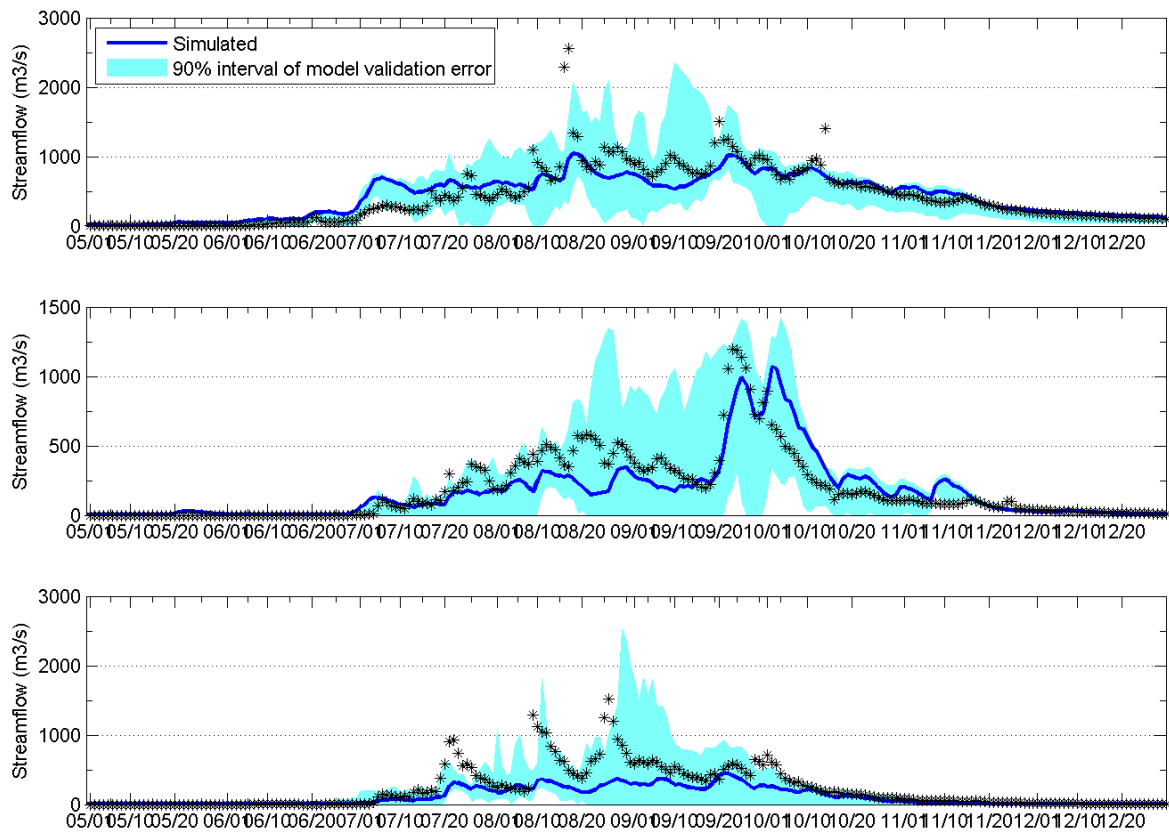


Figure 8: Streamflow simulations, uncertainty range and observations for the three watersheds of the Senegal Basin: the Bafing (top), Faleme (middle) and Bakoye (below).

This work presents an original compilation of hydrologic model simulations using rain gauges and different satellite precipitation products with three types of corrections in three watersheds of the Senegal basin with different climatic and hydrologic characteristics. It provides some insights as to the use of bias correction methods, the re-calibration of models for each new input dataset and the performance of lumped models in different watersheds in comparison with a complex distributed model.

Information Transfer Program Introduction

The WRRC maintains a strong and well-regarded Information Transfer Program consisting of regular and occasional publications, a series of informational events including an annual conference, outreach associated with applied research programs, a web site and consistent communication through electronic media. The diversity of information transfer modes mirrors the diversity of topics and audiences the WRRC addresses. Close ties with the water resources community in Arizona ensure the WRRC engages with issues of pressing concern to the state while continuing to serve the many various needs for relevant water resources information.

WRRC Information Transfer

Basic Information

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Descriptors:	None
Principal Investigators:	Sharon B. Megdal, Susanna Eden

Publications

1. Ajibode, O.M, C. Rock, K. Bright, J.E.T. McLain, C.P. Gerba, I.L. Pepper (2013) Influence of residence time of reclaimed water within distribution systems on water quality, Journal of Water Reuse and Desalination, in press; DOI: 10.2166/wrd.2013.088.
2. Al-Mashaqbeh, O., A.M. Ghair and S.B. Megdal, Performance of Grey Water Pilot Plant Using a Multi-Layer Filter of natural Materials for Agricultural Purposes in the Jordan Valley, CLEAN - Soil, Air, Water, September 17, 2013.
3. Cusimano J., Megdal, S.B., McLain, J.E. and Silvertooth, J.C., Study Finds Land Fallowing Improves Soil Quality in PVID, Arizona Water Resource, Winter 2014.
4. Eden, Susanna, J. Moxley and J. Cleveland, Desert Water Harvesting Initiative: Rainwater and Stormwater Harvesting, Green Infrastructure and Low Impact Development for Improved Sustainability and Adaption to Climate Change, Kachina News, 2pp., Arizona Water Association, June 4, 2013.
5. Gallo, E.L., P.D. Brooks, K.A. Lohse, J.E.T. McLain (2013), Temporal patterns and controls on runoff magnitude and solution chemistry of urban catchments in the semiarid southwestern United States. Hydrological Processes, 27: 995-110; DOI: 10.1002/hyp.9199.
6. Gerlak, Andrea K., Sharon B. Megdal, Robert G. Varady and Hunter Richards, Groundwater Governance in the U.S.: Summary of Initial Survey Results, Water Resources Research Center, May 2013. Available at <http://wrrc.arizona.edu/groundwater>.
7. Kabiri, L., A. Alum, C. Rock, J.E. McLain, M. Abbaszadegan (2013) Isolation of Bacteroides from fish and human fecal samples for identification of unique molecular markers, Canadian Journal of Microbiology, 59: 771-777; DOI: 10.1139/cjm-2013-0518.
8. Leal-Bautistia, R.M., M. Lenczewski, A. Gahala, J.E. McLain (2013) Assessing fecal contamination in groundwater from the Tulum Region, Quintana Roo, Mexico. Journal of Environmental Protection, 4: 1272-1279; DOI: 10.4236/jep.2013.411148
9. McLain, J. (2013), "Dinner for six" at the Annual Meetings. Crop, Soils, Agronomy News, 58(8): 38.
10. McLain, J. (2013), Integrity and ethics: meeting the career challenges that lie ahead. Crop, Soils, Agronomy News, 58(12): 34-35.
11. Megdal, Sharon B., Key Messages for CRWUA Highlight Arizona's Achievements, Yet More Efforts Are Needed, Arizona Water Resource, Winter 2014.
12. Megdal, Sharon B., On Defining and Achieving Water Security, Arizona Water Resource, Water Resources Research Center, Spring 2013.

WRRC Information Transfer

13. Megdal, Sharon B., Shortage Projections May Inspire Changes in Thinking, Arizona Water Resource, Water Resources Research Center, Fall 2013.
14. Megdal, Sharon B., Written from Sea, Arizona Water Resource, Water Resources Research Center, Summer 2013.
15. Megdal, Sharon B., "The role of the public and private sectors in water provision in Arizona, USA," in *The Future of Public Water Governance: Has Water Privatization Peaked?*, Christopher A. Scott and Bernard de Gouvello, eds., Routledge Special Issues on Water Policy and Governance Series, Taylor and Francis, ISBN-13: 9780415713139. February 2014. (Reprint of article previously published in *Water International*.)
16. Radonic, Lucero, Drought Along the Rio Grande Drought Highlights Water Management Complexities, Feature, Arizona Water Resource, Summer 2013.
17. Raghav, Madhumitha, S. Eden, K. Mitchell and B. Witte, Arroyo 2013 Contaminants of Emerging Concern in Water, Arroyo, 12pp., Water Resources Research Center, 2013.
18. Schwartz, Kerry and Nicole R. Ritter, Kids Learn, Communities Benefit, July 2013, IMPACT Vol. 15 No. 4, American Water Resources Association.
19. Wall, G.W., J.E.T. McLain, B.A. Kimball, J.W. White, M.J. Ottman, R.L. Garcia (2013) Infrared warming affects intrarow soil carbon dioxide efflux during vegetative growth of spring wheat. *Agronomy Journal*, 105: 607-618; DOI: 10.2134/agronj2012.0356.
20. Witte, Becky, New Members Share Thoughts and Goals for CAWCD Board, Arizona Water Resource, Water Resources Research Center, Winter 2013.

University of Arizona Water Resources Research Center Information Transfer Program

During the reporting period, the WRRC's Information Transfer Program continued to produce its major component products. These include the Arizona Water Resource and Arroyo newsletters, the Annual Conference, Brown Bag seminars, and the website.

The highly regarded quarterly newsletter, Arizona Water Resource (AWR), is a keystone of the WRRC's Information Transfer program. The AWR was redesigned for full-color and the first redesigned issue appeared in Fall 2013. The AWR provides timely information on water resources news, including current research, law and policy developments, publications, and other items of interest to subscribers of both its print and email editions. Each year the AWR includes summaries of 104(b) research projects. Issues appear quarterly in January, April, July and October.

The practice of including supplemental inserts by affiliated programs and external organizations also continued. The AWR published full-color, four-page inserts including an insert provided by the USGS Water Science Center for the Winter 2014 issue. Although long-term plans call for an on-line only newsletter, in 2013-14 a print edition continued to be sent to its approximately 2,200 subscribers. Several feature articles were written by our Graduate Outreach Assistants Katharine Mitchell, who graduated in May with Master of Planning degree, and Lucero Radonic, a PhD student in the Department of Anthropology. The AWR also highlighted outcomes from the WRRC's Annual Conference and published Guest Views by Evan Canfield, Pima County Regional Flood Control District, and Irene Ogata, City of Tucson; Summer Waters, Nick Pacini and Ayman Mostafa, UA Cooperative Extension, Maricopa County; Katosha Nakai, Esq., Central Arizona Project Manager, Tribal Relations & Policy Development, Robert G. Varady and Christopher A. Scott from UA. In addition, the AWR provided an opportunity to showcase the students who work at the WRRC and to publish the winners of our photo contest, "Water: the Human Element."

The Arroyo, WRRC's annual newsletter on a single topic of timely interest to Arizona, was published in the spring of 2013. Titled "Contaminants of Emerging Concern in Water," the Arroyo introduced the concept of emerging contaminants, explaining the various terms used and their overlapping meanings. It described the results of numerous studies into exposure and potential effects and raised the need for additional research. As usual, every attempt was made to present a balanced perspective, and the draft was reviewed by a variety of experts before publication, including Guy Carpenter, Carollo Engineers; Chuck Graf, Arizona Department of Environmental Quality; Brad Hill, City of Flagstaff; John Kmiec, Town of Marana; Jean McLain, University of Arizona; David Quanrud, University of Arizona; Dan Quintanar, City of Tucson; and Channah Rock, University of Arizona.

The Arroyo was written by Madhumitha Raghav, the 2012 Montgomery & Associates Summer Writing Intern at the WRRC, along with Susanna Eden and graduate students Katharine Mitchell and Becky Witte. Madhumitha Raghav was a PhD student in Environmental Engineering at UA, who received her degree in December 2012. The Montgomery & Associates Internship is a competitive award made possible with funding from Montgomery &

Associates, Water Resource Consultants. The competition is open to any student enrolled in one of the three Arizona universities. Planned as an annual opportunity for a student to learn from experience working with WRRC personnel, the internship supports one student each summer. The applications process calls for a writing sample, statement of goals, and a letter of recommendation. The 2013 Summer Intern was Max Effrein, who received his BA in Journalism and History in May 2014. His research for the 2014 Arroyo was on the value of water, including water prices and costs in various sectors, the value of water in the environment, the concept of virtual water. Following additional research and revisions during winter 2013-14, a draft was sent to outside reviewers for comments. Reviewers included Kathleen Ferris, Arizona Municipal Water Users Association, Patrick Graham, The Nature Conservancy, Leslie Meyers, U.S. Bureau of Reclamation, Cliff Neal, City of Phoenix, Bill Plummer, Agribusiness Council of Arizona, Dave Roberts, Salt River Project, Ben Rudell, Arizona State University Global Institute of Sustainability, Ken Seashole, Central Arizona Project, and Margaret Wilder, UA Udall Center for Studies in Public Policy. Revisions based on reviewer comments were incorporated and the Arroyo was planned for publication and distribution in spring 2014. The WRRC's External Advisory Committee has selected the Arroyo topic in the past few years and the topic selected for 2015 is closing the projected gap between water supply and demand in Arizona.

The WRRC's Annual Conference for 2014 will be held in April in collaboration with the Arizona Department of Water Resources. The conference, "Closing the Gap Between Water Supply and Demand," will explore the water supply challenges and a range of options to balance the scales of water supply and demand in Arizona. The conference will be held at the University of Arizona's Student Union Memorial Center in Tucson, for an estimated 300 participants.

The 2013 Annual Conference, "Water Security, From the Ground Up," was held March 5th at the UA Student Union Memorial Center. Organized in partnership with the United States Geological Survey, it featured prominent water experts on water sustainability, environmental implications of stressed water supplies, policy options, and aspects of water security from the local to the global scale. Anthony Cox, Head of the Climate, Biodiversity and Water Division in the OECD Environment Directorate, opened the Conference with a presentation on the global perspective of water security. Twenty-one posters were on display during the conference and at the lunchtime poster session. The three student poster winners were 1st Place - Rachel Maxwell; 2nd Place - Angela Knerl; and 3rd Place - Jeremy Cusimano, all from UA. Cash poster prizes were provided by the Water Sustainability Program. In addition to WSP, our sponsors included Aquasec, Agribusiness Council of Arizona, APS, BKW Farms, CAP, Metropolitan Pima Alliance, Montgomery & Associates, SRP, USGS, and Veolia Water. More than 300 people attended and the conference was featured on "Arizona Week" with Michael Chihak, who spoke with WRRC Director Sharon B. Megdal and several of the speakers. Participants included attendees from 37 communities in Arizona, five other US states and two other countries.

The 2014 Conference, *Closing the Gap Between Water Supply and Demand*, scheduled for Tuesday, April 8th, 2014 at the UA Student Union Memorial Center. Planning for the conference began in the spring of 2013. For the year 2014, WRRC's 50th Anniversary, the

conference is being organized in collaboration with the Arizona Department of Water Resources. The Colorado River Basin states are currently engaged in a process exploring the range of potential options for balancing the water supply and demand scales. The WRRC 2014 Conference will focus this exploration on our state. Water experts will present the latest information on a menu of options, such as reuse, conservation, transactions, and technological methods, to be considered for closing the supply-demand gap. The day will close with a panel of thought leaders discussing the issue—Closing the Gap: Can we do it? Hear the prognosis in a question and answer session led by Sharon B. Megdal. Registration opened the first week of December. Communications efforts for the Annual Conference are under way and include the creation of an interactive web page (wrrc.arizona.edu/conference), print and web promotional materials, e-news announcements, calendar listings, and a promotional video. This conference will also commemorate the WRRC's 50th anniversary.

Collaborations will continue with the Water Sustainability Program, now a part of the Water, Environmental and Energy Solutions Initiative, and with Arizona Project WET. Ongoing programs of research and outreach will continue and be expanded. In Fall 2013, the Environmental Water Program changed its name to Water Research and Planning Innovations for Dryland Systems (Water RAPIDS). The Water RAPIDS program focuses on new approaches to water resource management that integrate traditional planning for natural resources with land use planning. It includes Conserve to Enhance (C2E), a unique, voluntary program that motivates consumers to use water more efficiently by linking water conservation efforts with environmental enhancement in their community and region. A second Water RAPIDS project is Connecting Environmental Water Needs to Arizona Water Planning (EnWaP), which engages individuals and groups at the local, regional and state levels to explore what it means to consider the environment in water management and planning. Participatory Watershed Assessment for the Upper Gila River is a partnership with the Gila Watershed Partnership (GWP) and Arizona Cooperative Extension that is developing decision-making tools to support watershed planning for Arizona's portion of the Upper Gila River watershed. Outreach is also a major function of other research projects including a desert water harvesting initiative to enhance outreach and communication among utilities, practitioners, academics, and interested citizens; and another that uses an innovative modeling framework and robust stakeholder engagement strategies to help water managers understand the potential impacts of future climate on groundwater resources. These programs are almost entirely funded from non-program sources, but they will be provided support by the Information Transfer Program.

The WRRC continued its expanded series of Brown Bag Seminars, which attracts varied audiences. The Brown Bag Seminars provide a forum for researchers, students and community members to learn about and discuss water resources issues. In 2013, the WRRC has held 16 Brown Bag seminars featuring experts from Arizona, the Southwest and included several eminent authorities from Israel. Average attendance was 30 people (in person), approximately 60 percent from UA and 40 percent from the broader community. Also in 2013, access to the WRRC's Brown Bag series expanded to include offsite stakeholders through live webcasts via Blackboard Collaborate and in-house video coverage. We have had 35 participants avail themselves of remote observation. Brown Bag Seminars from the reporting period are listed below.

- March 8, 2013, David B. Brooks, Natural Resource Economist, International Development Research Centre (IDRC), Canada (retired), *An Agreement to Share Water Between Israelis and Palestinians: The FoEME (Friends of the Earth Middle East)*
- March 20, 2013, Ruth Valencia, Principal Scientist, Biological & Cultural Resource Services and Steve Westwood, Water Rights Analyst, Salt River Project, *An Unexpected Alliance: A conversation with Salt River Project about collaborative efforts to protect habitat and surface water flows on the Lower San Pedro River*
- April 19, 2013, Fernando B. Molina, Public Information Officer; Sandy Elder, Deputy Director, Tucson Water, *Tucson Water IBM Smarter Cities Challenge Grant*
- April 24, 2013, Dave D. White, Co-Director, Decision Center for a Desert City; Senior Sustainability Scientist, Global Institute of Sustainability, Arizona State University, *Linking Knowledge and Action for Water Sustainability and Urban Climate Adaptation: Research Update from the ASU Decision Center for a Desert City*
- April 26, 2013, Jamie McEvoy, Ph.D. Candidate, School of Geography and Development, UA, *Is Desalination the Solution to Water Security? The Promise and Perils of a Technological Fix to the Water Crisis in Baja California and Sur, Mexico*
- August 19, 2013, Professor Amit Gross, visiting scientist from Ben Gurion University of the Negev (Israel), *Scarce Water Resources and Development of Appropriate Decentralized Technologies for Sustainable Water Supply in the Negev Desert*
- September 12, 2013, Nathan Bracken, Legal Counsel for the Western States Water Council (WSWC), *Western Water Challenges and the Role of Water Transfers*
- September 27, 2013, Shaul Sorek, Ben-Gurion University, Israel, *The Reason for Unreasonableness in Groundwater Quality Management*
- October 10, 2013, Benjamin Ruddell, Assistant Professor, Arizona State University, *Water Resource Impacts Embedded in the Western U.S. Electrical Energy Trade (Current Patterns and Adaptation to Future Drought)*
- November 6, 2013, Katie Meehan, Assistant Professor, Department of Geography, University of Oregon, *Downspout Politics, Upstream Conflict: Contested Legal Geographies of Rainwater Harvesting in the U.S.*
- November 8, 2013, Christa McJunkin, SRP Senior Water Resource Analyst Jason Hauter, Akin, Gump, Strauss, Hauer & Feld LLP, *SRP & GRIC: Gila River Water Storage and Water Planning for the Community and Arizona*
- December 9, 2013, Ron Elkins, Wetlands Process Control Specialist for City of Phoenix Tres Rios Flow Regulating Wetlands, *Tres Rios - Wetland Ecology in an Arid Environment*
- January 24, 2014, Chris Udall, Executive Director, Agri-Business Council of Arizona, *Agri-Business Council of Arizona's Perspective on Water and Agriculture in Arizona*
- February 5, 2014, Larry Stevens, Program Manager, Springs Stewardship Institute, Museum of Northern Arizona, *Where Groundwater Meets the Sky: Springs Ecosystem Ecology and Stewardship*
- February 21, 2014, Kathryn Sorensen, Water Services Director, City of Phoenix, *Phoenix's Water Supply Resiliency*
- February 25, 2014, Tim Cervantes, Administrative Director, The Cochise Water Project (TCWP), Dave Grieshop, Chair TCWP Technical Advisory Committee, *The Cochise Water Project: Synergy at Work*

Other Outreach Events

March 2013 a workshop was held at the WRRC, for grant-writing to support gray water research with scientists in Jordan. Workshop participants included Dr. Ayoup Ghrair of the Royal Scientific Society of Jordan, and Chuck Graf of the Arizona Department of Environmental Quality.

The WRRC provided in-kind support for the Tucson Arts Brigade's community event, The Water Festival: Synergy of Art, Science, and Community on April 21, 2013. The Water Festival is a large-scale community event in Pima County that showcases creativity and water solutions together and is a prime opportunity to engage the public through diverse activities for learning, networking, and family fun!

Also on April 21, 2013, the WRRC co-sponsored Tucson's 19th Annual Earth Day Festival and Parade on the theme of "Green Planet, Green Future". The event encouraged people to dress up as plants, animals, insects, etc. and watch a parade of sustainable and environmentally themed floats. Other highlights included an alternative fuel vehicle show, solar competition and music.

On April 24, 2013 the WRRC Environment Program hosted its first Environmental Flows and Friends reading and discussion group. Meeting approximately monthly, the Flows and Friends group reads articles relevant to the specified topic before meeting for discussion. Topics have included litigation on the San Pedro River, the pulsed flow release for the Colorado River Delta, and the future of the Upper Gila River.

May 25, 2013 the WRRC co-sponsored a workshop at the UA Campus Ag Center, Karsten Turfgrass Center (Tucson, AZ) organized by Audubon's Western Rivers Action Network. The "Protecting Our Rivers" workshop (Tucson) was intended to gather interested participants in the Tucson area to promote healthy rivers in the Colorado River Basin. The WRRC also co-sponsored a "Protecting Our Rivers" workshop at the Nina Mason Pulliam Rio Salado Audubon Center in Phoenix, Ariz. on June 8, 2013, hosted by Audubon Arizona, Phoenix-area Audubon chapters, and Rio Salado Audubon Center. The workshops included overviews of critical issues facing western rivers and habitats, a presentation about the WRAN's policy priorities and Arizona river protection efforts, and an afternoon devoted to effective advocacy.

On Friday of Homecoming Weekend, November 8, 2013, a Collegiate and Campus Showcase program screened the film "Seeking Water From the Sun" and presented a panel discussion to discuss the making of the film. The event co-sponsors were WRRC, WSP, Renewable Energy Network, and Arizona Public Media.

The WRRC partnered with the Water Sustainability Program (WSP) on the WSP Distinguished Speaker Series. On November 13, Dr. Alon Tal (Ben Gurion University, Israel) spoke on "Triumph or Tragedy? A Brief History of Water Management in Israel," at the UA Center for Creative Photography Auditorium. Co-Sponsors included WSP, WRRC, the Center for Middle Eastern Studies, the Udall Center for Studies in Public Policy, and the Ralph and Sally Duchin Campus Lectureship Series for the Arizona Center for Judaic Studies. There were 80 attendees.

Also on November 13, 2013, the WRRC and WSP hosted a roundtable discussion with Alon

Tal in the WRRC Sol Resnick Conference Room. Attendees represented Pima County, City of Tucson, Institute of Sustainable Cities, WRRC and other units of UA.

The WRRC convened a meeting of UA faculty and federal agency personnel on November 15, 2013 to discuss ideas for generating additional binational research on Arizona's border with Mexico. Commissioners Drusina and Salmon of IBWC/CILA attended.

Raanan Adin spoke about Israel's Water Technology and Industry - Roots, Growth, Sustainability, at a roundtable sponsored by WRRC and WSP in the WRRC Sol Resnick Conference Room, with 20 attendees from the private sector, Tech Launch Arizona, City of Tucson and other UA units, November 22, 2013.

Transforming Research Into Practice: Finding Solutions to Arizona Water Challenges, a one-day workshop, organized by the Research Committee of AZ Water, in association with the UA WRRC was held on January 15, 2014. The workshop consisted of a day of speakers representing research providers and research users and was highlighted by a post session/networking opportunity.

Second in the WSP Distinguished Speaker Series co-sponsored by the WRRC, Stanley Pollack, Assistant Attorney General, Water Rights Unit, Navajo Nation Department of Justice presented "Little Colorado River – Failure of the Settlement and the Triumph of Social Media," on January 30, 2014 held at the UA College of Law.

February 14, 2014, The WRRC held its Annual Chocolate Fest, coupling it with a 50th Anniversary Celebration. Attended by two immediate past directors of the WRRC, Hannah J. Cortner and Peter Wierenga, the informal gathering gave current and former members and friends of the WRRC a chance to reminisce and renew ties over a feast of chocolate.

Website and electronic communication

In keeping with general trends in communication, the WRRC is placing increased emphasis on the internet as a public information tool. Communications efforts at the WRRC saw a number of changes in 2013. Notably, distribution of WRRC news and events switched to a regular weekly e-news digest format – The WRRC Weekly Wave. The Wave is a visually appealing, easily navigable informational email sent each Friday, containing WRRC and water community events, news, announcements, media coverage, and social media links. WRRC news and events also regularly appear in newsletters from the College of Agriculture and Life Sciences, UA Extension, Institute of the Environment, ASU Sustainability Digest and more. WRRC social media efforts have expanded, with growing interest in the WRRC's Facebook presence (facebook.com/AZWRRC) and a recent revival of the @AZWRRC Twitter handle. Most content on the WRRC website is now also easily shareable on Facebook with the addition of a "Share" button.

The WRRC newsletters were posted along with other community resources, including 104(b) final project reports. Brown Bag seminars were also posted and are easily retrieved, as are WRRC conference presentations. The WRRC website – wrrc.arizona.edu – added Media/Press

pages and maintains a fresh portfolio of homepage feature news stories. The addition of an on-site WRRC weather app and an UA Water Expertise Directory, which contains more than 300 experts searchable by name, field and department, has helped boost website traffic. The directory of WRRC staff can be found at <http://wrrc.arizona.edu/personnel-directory>. The water events calendar is updated on a regular basis and the personnel directory is kept up-to-date with current WRRC faculty, staff and students. Registration for the WRRC conference is made available on the web site through expanded and enhanced Annual Conference pages. Fillable forms and instructions for applications and proposals, including the WRA 104(b) research proposals are accessible through the website. The Director's page (<http://wrrc.arizona.edu/sharon-b-megdal>) includes a drop-down menu of all of Sharon B. Megdal's public policy columns.

Individual program pages have seen modifications throughout the year with the addition of several program sections, including those for the, the Desert Water Harvesting Initiative, Various programs of research and outreach are supported with dedicated web pages that can be maintained by the program principals. These include the Water Research and Planning Innovations for Dryland Systems (Water RAPIDS) program, the Desert Water Harvesting Initiative and the Groundwater, Climate and Stakeholder Engagement (GCASE) program. A website for the Arizona component of the U.S.-Mexico Transboundary Aquifer Assessment Program is supported by the WRRC and linked through the WRRC website.

The WRRC is expanding efforts to consistently brand itself through design of materials in print and other media, including banners, folders, bookmarks, and rack cards. The WRRC implemented a new video editing station, allowing the WRRC to create videos and film in-house events. The second WRRC Annual Report was produced in 2013 for calendar year 2012 and a 2013 Report is planned.

Collaboration with the WRRC-based Arizona Project WET (Water Education for Teachers) has been mutually beneficial in expanding the reach and effectiveness of outreach and education projects, and this collaborative relationship will continue in the up-coming project year. A comprehensive water education program with established relationships with school districts and communities throughout Arizona, Arizona Project WET reaches out to teachers and students across Arizona by providing programs, workshops, mentoring and partnership activities. The WRRC and Arizona Project WET continued to work toward increase program integration.

In addition to all of the above, WRRC personnel carried out various public service activities. They are called upon regularly to give lectures and make presentations to diverse audiences across Arizona. They often collaborate with local, state, regional and federal agencies and organizations, as a resource for general information and as partners on specific projects. WRRC personnel participate on community and regional boards and commissions, serve on state and local task forces and study committees, and regularly attend important water resources meetings. In addition, the WRRC extends its research, outreach and education role through its collaboration with the university-wide Water Sustainability Program, a component of the Water, Environmental and Energy Solutions (WEES) initiative. The WRRC Director serves as one of two co-Director of WEES. WRRC personnel also respond to inquiries from the public on issues of concern. The WRRC facility is open to the public and provides information on water related topics to the public and a space for water related meetings.

The following is a list of presentations for Information Transfer on 104b and 104S projects:

Project Number: 2013AZ517B

Title: Extraction Methods for Engineered Nanoparticles From Aqueous Environmental Samples

- Westerhoff, P., Yang, Y., Bi, X.Y., Herckes, P., Hristovski, K. 2013. Nano Prospecting Across the Urban Water Gradient”, Gordon Research Conference, Stowe, VT.
- Yang, Y., Hristovski, K., Westerhoff, P., 2013. Cloud-Point Extraction and Characterization of Nanomaterials from Water, Tele Seminar of SRC Engineering Research Center for Environmentally Benign Semiconductor Manufacturing.

Project Number: 2013AZ516B

Title: Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater

- Quanrud, D. Estrogenic activity and emerging contaminants in the Lower Santa Cruz River, Arizona. Presented at *Friends of the Santa Cruz River Researchers Day*. Tucson, AZ, April 15, 2013.

Project Number: 2013AZ512B

Title: Do Simple Carbon Additions Reduce Resistance to Antibiotics in Environmental Bacteria?

- McLain, J.E. Antibiotic resistance and recycled municipal wastewater: is there a link? Pima Association of Governments Seminar Series, Tucson, Arizona; March 31, 2014.
- McLain, J.E. Public health and environmental safety of recycled municipal wastewater: current research. Osher Lifelong Learning (OLLI) Institute at the University of Arizona, Green Valley, Arizona; February 26, 2014.
- McLain, J.E., L. Durso, D. Snow. Antibiotic resistance in agricultural environments: a call to action. ASA-CSSA-SSSA Annual International Meetings, Tampa, Florida; November 5, 2013.
- McLain, J.E. Antibiotic resistance and recycled municipal wastewater: is there a link? Pima County (Arizona) Regional Flood Control District Monthly Brown Bag Series; October 2, 2013.
- McLain, J.E. Health effects of long-term irrigation with recycled municipal wastewater: are we spreading antibiotic resistance to our food supply? The University of Arizona School of Plant Sciences Interdisciplinary Seminar Series; October 1, 2013.
- McLain, J.E. Antibiotic resistance and recycled municipal wastewater: is there a link? University of Arizona School of Agricultural and Biosystems Engineering Seminar Series; September 30, 2013.

Project Number: 2013AZ513B

Title: Improving Hydrologic Investigations for Decision Support through Multi-Model

Analysis and Discriminatory Data Collection (MMA-DDC)

- Kikuchi, C.P., T.P.A. Ferre, T. Bayley, S. Hundt. 2012. Discrimination-Inference to Reduce Expected Cost Technique: Application to groundwater-surface water investigations. American Geophysical Union Fall 2012 Meeting, Invited Talk, Dec. 3-7.
- Kikuchi, C., T.P.A. Ferré, and J.A.Vrugt. 2011. Multiple model analysis with discriminatory data collection (MMA-DDC): A new method for improving measurement selection. American Geophysical Union Fall Meeting, 2011, San Francisco, CA, Dec. 5-9.
- Ferre, T.P.A., C. Kikuchi, J.A. Vrugt. 2014. Making the Right Measurements for the Right Reasons – Reconsidering Hydrogeophysics in the Context of Measurement Network Design. European Geophysical Union, Vienna, Austria, April 26-May 1.
- Ferre, T.P.A.. 2014. Making the Right Measurements for the Right Reasons – the Role of Hydrogeologists in Decision Making. Invited talk, University of Rennes, France.
- Ferre, T.P.A.. 2014. Making the Right Measurements for the Right Reasons – Merging the Theoretical and the Practical. Invited talk, University of Copenhagen, Denmark.

Project Number: 2013AZ519S

Title: Integrating African Hydrologic Initiatives Using Satellite Products to Support Water Monitoring and Forecasting in Africa

- Serrat-Capdevila, Aleix, Ashutosh Limaye, David Toll (2013), Improving Water Management and Addressing Transboundary Water Issues with NASA-USAID 'SERVIR' (on behalf of the SERVIR Applied Sciences Team), Stockholm World Water Week, 1-7 of September 2013, Stockholm (Sweden).
- Serrat-Capdevila, Aleix, Manuel Merino, Khalidou Ba, Juan B Valdes, Matej Durcik, (2013) Hydrologic simulations in three poorly-gauged watersheds of the Senegal Basin, using a lumped and a distributed model with different rainfall inputs. American Geophysical Union Meeting of the Americas, 14-17 May, Cancun (Mexico).
- Merino, Manuel, Aleix Serrat-Capdevila, Juan B Valdes, Matej Durcik (2013) Evaluation of the Performance of Satellite Precipitation Products over Africa. American Geophysical Union Meeting of the Americas, 14-17 May, Cancun (Mexico).
- Serrat-Capdevila, Aleix, Session Organizer and Chair, Advances in Satellite Precipitation and Hydrologic Applications. American Geophysical Union, Meeting of the Americas, 14-17 of May 2013, Cancun (Mexico) with co-conveners Khalidou M. Ba (CIRA-International Center of Water Resources, Mexico), Justin Sheffield (Univ. of Princeton), Soorosh Sorooshian (Univ. of California, Irvine).
- Serrat-Capdevila, Aleix, Presenter: Streamflow forecasting efforts and the SERVIR SWAAT Project, Participant: UNESCO Drought Monitoring Workshop, Niamey (Niger), October 2013 with AGRHYMET Regional Center and the University of Princeton.
- Serrat-Capdevila, Aleix, Presenter: Remote Sensing for Climate Change Analysis and Adaptation and Facilitator: A road map for Climate Change Adaptation for the Nile, Participant: UNESCO workshop: Water for Peace in Africa Program, Dar es Salam (Tanzania) December 2013.

Presentations by WRRRC personnel (chronological order)

March 2013, Sharon B. Megdal, Interview and feature in Tucson Water Bill Insert, “Focus on UA-Utility Partnership,” distributed to all Tucson Water customers through the bill insert, Tucson AZ.

March 4, 2013, Aaron Lien, EnWaP and various approaches to landscape scale planning and conservation, Winkelman Natural Resources Conservation District Board, Winkelman, AZ.

March 5, 2013, Sharon B. Megdal, Conference Convener/Moderator, Water Security from the Ground Up, Water Resources Research Center Annual Conference, University of Arizona, Tucson, AZ.

March 6, 2013, Candice Rupprecht and Aaron Lien, Conserve to Enhance, Colorado River Delta Water Trust.

Recorded March 5, 2013, Aired March 8, 2013, Sharon B. Megdal, Interview, Arizona Week, Michael Chihak, Host, KUAT TV, PBS Channel 6, Tucson AZ.

March 13, 2013, Brittany Xiu, WRRC projects and outreach in Arizona, Master Watershed Steward classes at Round Valley High School, Eagar, AZ.

March 15, 2013, Sharon B. Megdal, Presentation, Arizona Water 101: A Look at Arizona Water Issues, Staff of Arizona Congressional Offices, Phoenix, AZ.

March 20, 2013 (Meeting held March 19-21, 2013), Sharon B. Megdal, Presentation, Groundwater Governance in a Federal Framework: Results of a Survey of the 50 States of the USA, (Andrea Gerlak and Robert Varady, coauthors), Fifth Regional Consultation, GEF Groundwater Governance Project, The Hague, The Netherlands.

March 22, 2013, Sharon B. Megdal, Discussion Leader, The International Celebration of World Water Day 2013 on Water Cooperation, Breakout Session 3, Water cooperation helps preserve water resources and protect the environment, The Hague, The Netherlands.

March 26-27, 2013, Jean E. McLain, Roundtable Participant: Research Frontiers in Water Reuse: Removing Development Obstacles and Stimulating Innovation. Sponsored by Arizona State University Global Institute of Sustainability, Tempe AZ.

March 27-28, 2013, Sharon B. Megdal, Invited Participant, First Meeting of the OECD Water Governance Initiative, Organisation for Economic Co-operation and Development, Paris, France.

March 29, 2013, Jean E. McLain, Roundtable Participant: Sustainable Cities Workshop, sponsored by the UA College of Science and Biosphere, Tucson AZ.

April 9-12, 2013, Walston, S., Rock, C.M., Jean E. McLain, D. Gerrity, and L. Abrell, Does increasing solids retention time in the wastewater treatment process affect the persistence of antibiotic resistance genes? University of Arizona 2013 Earth Week Celebration, Tucson, AZ.

April 15, 2013, Jean E. McLain, Guest Lecture, Public Health and Environmental Safety of Recycled Municipal Wastewater – Current Research, SOS326 Sustainable Ecosystems, Arizona State University, Phoenix, AZ.

April 16, 2013, Candice Rupprecht, Conserve to Enhance: A tool for linking consumer water efficiency and urban wash enhancement in Tucson, 5th Annual Santa Cruz River Research Days at the Sonoran Desert Museum, Tucson, AZ.

April 17, 2013, Kelly Lacroix and Brittany Xiu, Available EnWaP information for the San Pedro River, Upper San Pedro Partnership Technical Advisory Committee, Sierra Vista, AZ.

April 21, 2013, Sharon B. Megdal, Presentation, Solutions to the water management challenges of Arizona and Israel, Technology Pavilion at the Israel Festival, Tucson, AZ.

April 23, 2013, Sharon B. Megdal, Presentation, Arizona-Israeli collaborative efforts to address

water management challenges: A cross-disciplinary approach, Meeting of the Technical Advisory Committee to the United States-Israel Binational Agricultural Research and Development Fund, Tucson, AZ.

April 24, 2013, Sharon B. Megdal, Presentation, Connecting water policy considerations to other water research and analysis, Center for Environmentally Sustainable Mining (CESM), Technical Advisory Committee Meeting, Tucson, AZ.

April 25, 2013, Candice Rupprecht and Brittany Xiu, Conserve to Enhance: Water Awareness, Ventana Medical Systems Earth Week event, Tucson, AZ.

April 28, 2013, Sharon B. Megdal, Presentation and Panelist, Israel, JNF and Water Solutions, Summit with NF, Las Vegas, NV.

April 30, 2013, Sharon B. Megdal, Panelist, Southern Arizona Water: Development, Growth and Sustainability, Real Estate and Allied Professions (REAP), Tucson, AZ.

May 1-3, 2013, Walston, S., Rock, C.M., Jean E. McLain, D. Gerrity, and L. Abrell, Does increasing solids retention time in the wastewater treatment process affect the persistence of antibiotic resistance genes? 86th Annual Arizona Water Conference, Glendale, AZ.

May 8, 2013, Kelly Lacroix, EnWaP, Drought and Arizona Rivers: Looking into the Past and Thinking About the Future, Pima County Local Impact Drought Group Meeting, Tucson, AZ.

May 15, 2013, Jean E. McLain, Presentation, Is Antibiotic Resistance a Useful Tool for Tracking Sources of Contamination in Yucatan Groundwater? American Geophysical Union Meeting of the Americas, Cancun, Mexico.

May 14-15, 2013, Sharon B. Megdal, Invited Expert Participant, GEF Transboundary Waters Assessment Programme (TWAP), Assessment of Transboundary Aquifers and SIDS Groundwater Systems, Inception Meeting, UNESCO Programme office for Global Water Assessment, Perugia Italy.

May 14-17, 2013, Jean E. McLain, M. Lenczewski, R. Leal-Bautista, Can antibiotic resistance analysis be a useful tool for tracking population sources of contamination in Yucatan groundwater? American Geophysical Union Meeting of the Americas, Cancun, MX.

May 18 - 21, 2013, Brassil, N., C. Rock, Jean E. McLain, and K. Nolte, Assessment of *Escherichia coli* as an Indicator of microbial quality of irrigation waters used for produce. American Society for Microbiology 113th Annual Conference, Denver, CO.

May 21, 2013, Jean E. McLain, N. Allen, L. Abrell, Assessing biological and chemical quality of harvested rainwater in Arizona: can in-line carbon filters decrease health risks?, Rainwater/Stormwater Professionals Network, WRRC Sol Resnick Conference Room, Tucson, AZ.

May 21, 2013, Kelly Lacroix, EnWaP, Environmental Water Demands in the Sky Island Region and Beyond: The AZ Environmental Flow Needs Database, Attendance, Presented at the Learning to Live with the Heat: Adapting to a Changing Climate in the Sky Island Region Conference May 21-22, Tucson, AZ.

May 24, 2013, Sharon B. Megdal, Keynote Speaker, Securing our Water Future: Challenges and Solutions, International Water Conference, Sias University, Zhengzhou, Henan Province, China.

June 5, 2013, Sharon B. Megdal, Presentation, Arizona Water Management Challenges and Solutions, Academy Village, Tucson, AZ.

June 8, 2013, Kelly Lacroix, Science on the Sonoita Plain, Environmental Flow Needs and Responses in the Cienega Creek Basin, Current Understanding and Research Gaps, Elgin,

AZ.

- June 8, 2013, Brittany Xiu, Water Challenges in the Colorado River Basin, News coverage available (Group holding workshops on Colorado River water supply: <http://www.azcentral.com/video/2467547091001>), Nina Masson Pullium Audubon Center (Phoenix, AZ), Western Rivers Action Network, 48, Audubon Arizona/WRAN.
- June 10-13, 2013, Kelly Lacroix, What is water for the environment and what can we do about it? Calculating and Considering Environmental Water Demands, American Water Works Association (AWWA) Annual Conference and Exposition, Denver, CO.
- June 12, 2013, Sharon B. Megdal, Presentation and panelist, Sharing the River: The Colorado River Compact and Water Banking, ACE2013, Annual Conference of the American Water Works Association, Denver, CO. Presentation posted in proceedings: <http://www.acumen-va-publish.com/awwaACE2013/contents.php?s=WED23>
- September 20, 2013, Susanna Eden, Presentation, Stakeholder Engagement in Model Development Incorporating Climate Change Uncertainty, 2013 Arizona Hydrological Society Symposium (September 18-21) Tucson, AZ.
- September 20, 2013, Candice Rupprecht and Brittany Xiu, Presentation, C2E Water Use Dashboard, Arizona Hydrological Society's Annual Conference, Tucson, AZ.
- September 23, 2013, Sharon B. Megdal, Presentation, Groundwater Management: A Policy Perspective, Annual Forum of the Groundwater Protection Council, Groundwater Protection: Reflecting Progress and Responding to the Future, St. Louis, MO.
- September 27, 2013, Sharon B. Megdal, Telephone Interview, 30-minute phone conversation with Doug McEachern of the Arizona Republic, Tucson AZ.
- September 30, 2013, Sharon B. Megdal, Media Interview, Water Future Looks Gloomy for Arizona, Surrounding Region, NPR, Tucson AZ.
- September 30, 2013, Jean E. McLain, Antibiotic resistance and recycled municipal wastewater: is there a link? University of Arizona School of Agricultural and Biosystems Engineering Seminar Series, Tucson AZ.
- October 1, 2013, Sharon B. Megdal, Interview, Arizona Illustrated, KUAT TV, Tucson, AZ.
- October 1, 2013, McLain, Jean E., Health effects of long-term irrigation with recycled municipal wastewater: are we spreading antibiotic resistance to our food supply? The University of Arizona School of Plant Sciences Interdisciplinary Seminar Series, Tucson AZ.
- October 1, 2013, Paul Crabtree, Water Harvesting and Wastewater Reuse at the Community Scale, Desert Water Harvesting Initiative hosted participation in a water harvesting webinar presented by Forester University.
- October 2, 2013, Jean E. McLain, Antibiotic resistance and recycled municipal wastewater: is there a link? Pima County (AZ) Regional Flood Control District Monthly Brown Bag Series.
- October 2, 2013, Schwartz, Kerry, "Do you know your urban water address -- and why it matters?", Water Smart Innovations Conference, Las Vegas, NV.
- October 3, 2013, Candice Rupprecht and Brittany Xiu, Presentation, C2E Water Use Dashboard, Water Smart Innovations 2013 Annual Conference, Las Vegas, NV.
- October 4, 2013, Sharon B. Megdal, Panelist, Water Efficiency and the Colorado River Basin Supply and Demand Imbalance, Water Smart Innovations Conference, Las Vegas, NV.
- October 8, 2013, Sharon B. Megdal, Panelist, VerdeXchange Water Panel, Scottsdale, AZ.
- October 11, 2013, McOmber, T.C., C.M. Rock, Jean E. McLain, and J.E. Curry, Poster

Presentation, Water quality improvements for Southern Arizona on the Upper Santa Cruz River. Fourth Annual University of Arizona Food Safety Consortium Meeting, Tucson, Arizona.

October 11, 2013, Jean E. McLain, Leader, University of Arizona Food Safety Consortium Annual Meeting, Omni Tucson Resort, Tucson, AZ.

October 11, 2013, Schwartz, Kerry, The Water Investigations Program (WIP): Using Water as an Integrating Context for STEM in the Classroom, Arizona Science Teachers Association Conference, Grand Canyon University, Phoenix, AZ.

October 11, 2013, Wilkening, Betsy, To the Poles & Beyond, Arizona Science Teachers Association Conference, Grand Canyon University, Phoenix, AZ.

October 12, 2013, Sleeper, Tina, Water Education Invigorates Classroom Learning with Common Core and STEM, Arizona Science Teachers Association Conference, Grand Canyon University, Phoenix, AZ.

October 12, 2013, Stoll, Mary Ann, Tired of Lecturing? Let the Students Take Charge!, Arizona Science Teachers Association Conference, Grand Canyon University, Phoenix, AZ.

October 12, 2013, Wilkening, Betsy and Kerry Schwartz, Agents of Change: Integrating Common Core with Unique Hands-On Science Projects, Arizona Science Teachers Association Conference, Grand Canyon University, Phoenix, AZ.

October 18, 2013, Sharon B. Megdal, Presentation, Water banks: Using managed aquifer recharge to meet water policy objectives, ISMAR8, 8th International Symposium on Managed Aquifer Recharge, S.B. Megdal, Peter Dillon (presenting), and Kenneth Seasholes, Beijing, China.

October 22, 2013, Sharon B. Megdal, Keynote Presentation, Useful Lessons from Transboundary Water Efforts along the United States-Mexico Border, WATEC 2013, Tel Aviv, Israel.

October 28, 2013, Jean E. McLain, Antibiotic resistance in agricultural environments: a call to action. Interview with Libby's Luncheonette Radio Program, WCHE1520AM, Westchester, PA.

November 2, 2013, Oakes, Tara, "The Water Investigation Program" presented to Master Watershed Stewards, Rio Salado Habitat Restoration Area, Phoenix, AZ.

November 3, 2013, Jean E. McLain, Invited Participant: Ninja Communications Science: Becoming the Messenger Workshop, Tampa Convention Center, Tampa, FL.

November 5, 2013, Sharon B. Megdal, Presentation, session organizer and moderator, Groundwater Governance in the U.S. - Results of a Survey of the 50 States, S.B. Megdal (presenting), A. Gerlak, R. Varady, American Water Resources Association Annual Water Resources Conference, Portland, OR.

November 5, 2013, Jean E. McLain, L. Durso, D. Snow, Antibiotic resistance in agricultural environments: A call to action. ASA-CSSA-SSSA Annual International Agronomy Meetings, Tampa, FL.

November 13, 2013, Sharon B. Megdal, Presentation, Water Policies of Israel and Arizona: Lessons Learned and Outstanding Challenges, Heartbeat of Israel Community Lecture Series, Tucson, AZ.

November 14, 2013, Sharon B. Megdal, Presentation, Water Cooperation along the United States- Mexico Border, Why Cooperate? An Interdisciplinary Panel sponsored by the University of Arizona Honors College and the National Endowment for the Humanities, The University of Arizona, Tucson, AZ.

November 14, 2013, Justice, Pamela, Groundwater Presentation to the Master Watershed

Stewards, Maricopa County Extension Office, Phoenix, AZ.

November 20, 2013, Sharon B. Megdal, Presentation and workshop host, Update on the Transboundary Aquifer Assessment Program (TAAP): Santa Cruz and San Pedro Aquifers, GCASE (Groundwater, Climate and Stakeholder Engagement) Workshop, Water Resources Research Center, Tucson, AZ.

November 21, 2013, Sharon B. Megdal with Eylon Shamir, Presentation, Incorporating Climate Information and Stakeholder Engagement in Groundwater Resources Planning and Management, National Webinar sponsored by NOAA-SARP et al.

November 22, 2013, Sharon B. Megdal, Presentation and Roundtable Moderator, Water Policies of Israel and Arizona, Water Innovation and Technology Commercialization Roundtable, Water Resources Research Center, Tucson, AZ.

December 10, 2013, Sharon B. Megdal, Presentation, The Role and Programs of the Water Resources Research Center, Verde Valley Ditch Associations/Companies Meeting, Cottonwood, AZ.

December 10, 2013, Schwartz, Kerry, Engaging the Community in Wise and Purposeful Use of Water, Arizona Hydrological Society Tucson monthly meeting, Montgomery and Associates Office, Tucson, AZ.

January 23, 2014, Brittany Xiu, Guest Lecture, Challenges and opportunities facing Arizona's water future, Prescott College, Prescott AZ.

January 24, 2014, Brittany Xiu, Presentation, The University of Arizona's SWES 195A: Careers in Environmental Science, Tucson, AZ.

January 29, 2014, Sharon B. Megdal, Presentation, Water 101 – How Full is Our Water Glass? Tucson Association of Realtors, Tucson, AZ.

January 29, 2014, Sharon B. Megdal, Presentation, Foothills Forum, Tucson, AZ.

January 29, 2014, Jean E. McLain, C. Rock, K. Farrell-Poe. Microbial indicators and onsite wastewater treatment systems: what do we really know? 2014 Southwest On-site Wastewater Conference, Laughlin, NV.

February 5, 2014, Jean E. McLain, Presentation, How to construct an effective presentation: it's not as hard as you think! SWES696a; Antibiotic resistance and reclaimed municipal wastewater: is there a link? USDA-ARS US Arid-Land.

February 10-12, 2014, Sharon B. Megdal, Chair, The National Institute of Water Resources Annual Meeting hosted by the University of Arizona Water Resources Research Center, Tucson, AZ.

February 17, 2014, Jean E. McLain, Presentation, Agricultural Research Center Seminar Series, Maricopa, AZ.

February 26, 2014, Jean E. McLain, Presentation, Public health and environmental safety of reclaimed municipal wastewater: current research. Osher Lifelong Learning (OLLI), WRRC Spring Water Class, Green Valley, AZ.

February 27, 2014, Sharon B. Megdal, Television interview by Ryan Haarer, Weekend rain won't solve long term drought issues, KVOA TV (aired February 28, 2014), Tucson AZ.

February 27, 2014, Sharon B. Megdal, Television interview, journalist Tony Davis.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	6	0	0	0	6
Masters	3	0	0	0	3
Ph.D.	7	0	0	0	7
Post-Doc.	1	0	0	0	1
Total	17	0	0	0	17

Notable Awards and Achievements

Sharon B. Megdal was elected to a three-year term on the Board of Directors of the Western Rural Development. Her term began January 2014 and will run through December 2016.

2013AZ513B - The project team developed a set of tools that allow stakeholders to define their priorities, hydrologists to use these priorities to target improved knowledge through data collection, and decision makers to make direct use of hydrologic models for risk-based decision making. These tools are being gathered into a single software package named Multi-Model Analysis with Discriminatory Data Collection (MMA-DDC). We have completed preliminary applications of MMA-DDC to research applications and to water resources and contaminant hydrogeologic applications.

2013AZ513B - Colin Kikuchi received the Harshbarger Fellowship (2013)

2013AZ516B - Itzel Marquez and Alberto Cuevas, received fellowships from CONACYT, Mexico.

2013AZ512B - This work contributed to a successful meeting grant proposal: J.E. McLain, L. Durso, D. Snow. Antibiotics in agroecosystems: state of the science. USDA/NIFA Agriculture and Food Research Initiative Competitive Grants Program; \$49,871 (2013 - 2014).

The 2013AZ519S project has created strong synergies with research institutes and projects spanning the African Continent, including West Africa and the Sahel, Eastern and Southern Africa. The investigators in this project are either involved or in communication with the following initiatives and efforts and a strong coordinating effort exists among the following initiatives:

- NASA SERVIR Africa awarded a 4 year project to the University of Arizona to develop streamflow forecasts and water monitoring tools in three pilot basins in East and Southern Africa. The project will take a multi-product and a multi-model approach to hydrologic simulations and intends to interact significantly with regional decision-makers to produce adapted and useful water resources monitoring and forecasting tools.
- The Surface Hydrology Group at Princeton University operates the experimental African drought monitor. It provides Africa-wide estimates of precipitation (using TMPA), min and max air temperature, wind speed, evaporation, runoff, base-flow and soil moisture by running the VIC model at 0.25 degree resolution. They are testing and calibrating this application regionally.
- NASA SERVIR and USAID have supported the development of some distributed models such as CREST (SERVIR) and the GeoSFM model by FEWS-Net (USAID-NOAA) for applications over Africa. FEWS-Net has been working in applications in Africa, bridging technical and human dimensions.
- The G-WADI program of UNESCO has been collaborating with the PERSIANN product and SAHRA in the development of the HyDis visualization tool, which shows the latest precipitation over the globe in near-real time.
- Regional Hydrometeorological and Climate Institutes such as AGRHYMET and the Climate Services Center of the Southern Africa Development Community, as well as Management authorities such as the OMVS (Senegal Basin) have essential ground data repositories and they provide the links with regional and local stakeholders and decision-makers.

Publications from Prior Years

1. 2005AZ89B ("Big Chino Basin 3-D Digital Hydrogeologic Framework Model ") - Articles in Refereed Scientific Journals - Fry, M.C, A.E.Springer, and P.J. Umhoefer, 2011. Hydrogeologic implications of a fault scaling relationship in bedrock aquifers, *Environmental and Engineering Geoscience.*, 17:4,377-389.
2. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Articles in Refereed Scientific Journals - Fernández N, Sierra-Alvarez R, Amils R, Field JA, Sanz JL. 2009. Compared microbiology of granular sludge under autotrophic, mixotrophic and heterotrophic denitrification conditions. *Water Sci. Technol.* 59(6):1227-36.
3. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Articles in Refereed Scientific Journals - Fernandez N, Sierra-Alvarez R, Field JA, Amils R, Sanz JL. 2008. Microbial community dynamics in a chemolithotrophic denitrification reactor inoculated with methanogenic granular sludge. *Chemosphere.* 70:462-474.
4. 2005AZ81B ("Treatment of Nitrate in Groundwater with Autotrophic Bioreactors") - Dissertations - Chairez Llamas, M.C. Application of Elemental Sulfur as Electron Donor for the Remediation of Water Contaminated with Nitrate and Bromate. 2006. Master of Science Thesis, Dept Chemical and Environmental Engineering, University of Arizona.
5. 2006AZ132B ("Perfluorinated Chemicals in Municipal Wastewater Treatment Plants in Arizona") - Articles in Refereed Scientific Journals - Ochoa-Herrera, V., and R. Sierra-Alvarez. 2008. Removal of perfluorinated surfactants by sorption onto granular activated carbon, zeolite and sludge. *Chemosphere.* 72:1588-1593.
6. 2006AZ132B ("Perfluorinated Chemicals in Municipal Wastewater Treatment Plants in Arizona") - Dissertations - Ochoa-Herrera, Valeria, 2006, Processes for the Removal of Perfluorooctane Sulfonate (PFOS) from Semiconductor Effluents, MS Thesis, Department of Chemical and Environmental Engineering, Univ. of Arizona, Tucson, Arizona. May 2006
7. 2006AZ132B ("Perfluorinated Chemicals in Municipal Wastewater Treatment Plants in Arizona") - Dissertations - Ochoa-Herrera, Valeria. 2008. Removal of perfluorooctane sulfonate (PFOS) and related compounds from industrial effluents PhD dissertation, Department of Chemical and Environmental Engineering, Univ. of Arizona, Tucson, Arizona. Nov. 2008
8. 2007AZ219B ("Geospatial Analysis of Urban Thermal Gradients: Application to Tucson Arizona s Projected Water Demand") - Articles in Refereed Scientific Journals - Halper, E., C.A. Scott, S. Yool. 2012. Correlating vegetation, water use and surface temperature in a semi-arid city: A multi-scale analysis of the impacts of irrigation by single-family residences. *Geographical Analysis* 44(3): 235-257, doi: 10.1111/j.1538-4632.2012.00846.x.
9. 2007AZ219B ("Geospatial Analysis of Urban Thermal Gradients: Application to Tucson Arizona s Projected Water Demand") - Conference Proceedings - Scott, C.A., E.B. Halper, S.R. Yool, A. Comrie. 2009. The evolution of urban heat island and water demand. In *Proceedings of the 89th Annual Meeting of the American Meteorological Society, Eighth Symposium on the Urban Environment*, Phoenix, AZ, January 11 – 15, 2009. ams.confex.com/ams/89annual/techprogram/paper_150343.htm.
10. 2007AZ219B ("Geospatial Analysis of Urban Thermal Gradients: Application to Tucson Arizona s Projected Water Demand") - Articles in Refereed Scientific Journals - Halper, E., R. Bark, C.A. Scott, S. Yool. In review. Effects of irrigated parks on outdoor residential water use in a semi-arid city. *Landscape and Urban Planning*.
11. 2007AZ213B ("Sources of Nitrate in Groundwaters of the Tucson Basin ") - Dissertations - Dejiwakh, Navid R. 2008. Using triple isotope system to determine nitrate sources and sinks to groundwaters of a mid-size semi-arid city: Tucson, Arizona (Master's Thesis). The University of Arizona, Tucson, AZ.
12. 2008AZ346B ("Database Creation: Transboundary San Pedro Valley Aquifer") - Articles in Refereed Scientific Journals - Scott, C.A., S. Megdal, L.A. Oroz, J. Callegary, P. Vandervoet. 2012. Effects of

- climate change and population growth on the transboundary Santa Cruz aquifer. *Climate Research* 51: 159–170, doi: 10.3354/cr01061.
13. 2008AZ346B ("Database Creation: Transboundary San Pedro Valley Aquifer") - Book Chapters - Vandervoet, P.L., S.B. Megdal, C.A. Scott. 2013. Los acuíferos transfronterizos Santa Cruz y San Pedro en Arizona y Sonora: Estado actual y análisis de meta-datos (The Santa Cruz and San Pedro transboundary aquifers of Arizona and Sonora: Current status and metadata analysis) In G. Cordova, J. Dutram, B. Lara, and J. Rodriguez (eds.) *Desarrollo humano transfronterizo: retos y oportunidades en la región Sonora-Arizona* (Transboundary human development: Challenges and opportunities in the Sonora-Arizona region). Universidad de Sonora. Hermosillo, Sonora, pp. 227-251.
 14. 2008AZ346B ("Database Creation: Transboundary San Pedro Valley Aquifer") - Other Publications - Callegary, J., S.B. Megdal, C.A. Scott, P.L. Vandervoet. 2013. Arizona/Sonora Section of the Transboundary Aquifer Assessment Program, in W.M. Alley (ed.) *Five-Year Interim Report of the United States – Mexico Transboundary Aquifer Assessment Program: 2007 – 2012*. U.S. Geological Survey Open-File Report 2013–1059, 31 p. <http://pubs.usgs.gov/of/2013/1059/>.
 15. 2009AZ297B ("The Ecohydrology and Management of Pinus Ponderosa Forests in the Southwest") - Dissertations - Kerhoulas, Lucy P. 2013. Seasonal water use, carbon storage, climatic sensitivity and management of southwester ponderosa pine forests. Ph.D. Dissertation, Northern Arizona University.
 16. 2009AZ297B ("The Ecohydrology and Management of Pinus Ponderosa Forests in the Southwest") - Articles in Refereed Scientific Journals - Kerhoulas, Lucy P., Thomas E. Kolb, Matthew D. Hurteau and George W. Koch. 2013. Managing climate change adaptation in forests: a case study from the U.S. Southwest. *Journal of Applied Ecology* 2013, 50, 1311–1320
 17. 2009AZ297B ("The Ecohydrology and Management of Pinus Ponderosa Forests in the Southwest") - Articles in Refereed Scientific Journals - Kerhoulas, Lucy P., Thomas E. Kolb, George W. Koch 2013. Tree size, stand density, and the source of water used across seasons by ponderosa pine in northern Arizona. *Forest Ecology and Management* 289: 425–433
 18. 2010AZ407B ("Sources and transport of nitrogen from sky-island ecosystems to groundwater basins") - Articles in Refereed Scientific Journals - Deiwakh, N., Meixner, T., Michalski, G., McIntosh, J.C. (2012) Using ¹⁷O to investigate nitrate sources and sinks in a semi-arid groundwater system. *Environmental Science and Technology*, vol. 46, 745-751, [dx.doi.org/10.1021/es203450z](https://doi.org/10.1021/es203450z).
 19. 2010AZ395B ("Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron") - Articles in Refereed Scientific Journals - Luna-Velasco A, Sierra-Alvarez R, Castro B, Field JA. 2010. Removal of nitrate and hexavalent uranium from groundwater by sequential treatment in bioreactors packed with elemental sulfur and zero-valent iron. *Biotechnol. Bioeng.* 107(6):933-942.
 20. 2010AZ395B ("Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron") - Articles in Refereed Scientific Journals - Tapia-Rodriguez A, Luna-Velasco A, Sierra-Alvarez R, Field JA. 2012. Toxicity of uranium to microbial communities in anaerobic biofilms. *Water Air Soil Pollut.* 223 (7):3859-3868.
 21. 2010AZ395B ("Bioremediation of Uranium Plumes with Nano-Scale Zero Valent Iron") - Articles in Refereed Scientific Journals - Tapia-Rodriguez A, Tordable-Martinez V, Sun W, Field JA, Sierra-Alvarez R. 2011. Uranium bioremediation in continuously fed upflow sand columns inoculated with anaerobic granules. *Biotechnol. Bioeng.* 108(11):2583-2591.
 22. 2011AZ431B ("Characterization of Chelating Agents in Non-regulated Water Sources on Navajo Lands") - Book Chapters - Campbell, N. R. and J. C. Ingram, *Characterization of ²³⁴U/²³⁸U Activity Ratios and Potential Inorganic Uranium Complexation Species in Unregulated Water Sources in the Southwest Region of the Navajo Reservation*, in *Water Reclamation and Sustainability*, Ed. S. Ahuja, Elsevier, 2014, pg 79-97.
 23. 2012AZ476B ("Fate of Emerging Nanoparticle Contaminants during Aquifer Recharge with Treated Wastewater") - Articles in Refereed Scientific Journals - Rottman, J., Sierra-Alvarez, R., Shadman, F. 2013. Real-time monitoring of nanoparticle retention in porous media. *Environ. Chem. Lett.* DOI 10.1007/s10311-012-0381-3

24. 2012AZ476B ("Fate of Emerging Nanoparticle Contaminants during Aquifer Recharge with Treated Wastewater") - Articles in Refereed Scientific Journals - Rottman, J., Platt, L., Sierra-Alvarez R, Shadman F. 2013. Removal of TiO₂ nanoparticles by porous media: effect of filtration media and water chemistry. Chem. Eng. J. 217(1):212-220.
25. 2012AZ476B ("Fate of Emerging Nanoparticle Contaminants during Aquifer Recharge with Treated Wastewater") - Dissertations - Rottman, Jeffrey, Fundamentals and application of porous media filtration for the removal of nanoparticles from industrial wastewater, PhD dissertation, Dept. Chemical and Environmental Engineering, The University of Arizona, December 2012
26. 2012AZ476B ("Fate of Emerging Nanoparticle Contaminants during Aquifer Recharge with Treated Wastewater") - Dissertations - Platt, Luis C., Removal of TiO₂ nanoparticles by porous media: effect of filtration media and water chemistry. MS thesis, Dept. Chemical and Environmental Engineering, The University of Arizona, August, 2013
27. 2011AZ450B ("Iodinated Disinfection By-product Formation from Water Reuse Practices") - Other Publications - Durazo, Armando and Shane A. Snyder, 2013. An Examination of the Presence, Formation, and Transformation of Volatile Halogenated Organic Species in Wastewater Extracts Using GC-ICP-MS, Department of Chemical and Environmental Engineering and the BIO5 Institute, The University of Arizona, Tucson, AZ.